AGRICULTURAL EROSION CONTROL STRUCTURES

A Design and Construction Manual

Publication 832

Ministry of Agriculture,
Food and Rural Affairs

Ontario

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Editor

Robert P. Stone, P. Eng., Ontario Ministry of Agriculture, Food and Rural Affairs

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Preface

This manual was prepared to assist contractors in the design, installation and maintenance of agricultural soil erosion control systems. The manual deals with the types and causes of agricultural erosion as well as the design, installation and maintenance of structures to control erosion.

An effort has been made to include the more common and traditional beneficial management practices associated with structural soil erosion control, along with an introduction and basic information on more progressive and innovative opportunities, such as soil bioengineering and other soft streambank erosion solutions. This material, along with more detailed technical information related to floodwater storage, is in the manual appendices.

This manual provides guidelines to contractors who install agricultural soil erosion control works. Although it may serve as a useful guide to engineers, it wasn't prepared as a basic engineering manual on erosion control. No attempt has been made to supply all basic theory and information. Consult additional reference material for a comprehensive discussion of erosion and erosion control structures.

Please note that any products or supplies identified are for example or illustrative purposes only and are not intended as endorsements.

All technical information developed in this manual is based on Ontario conditions.

The tables, charts and graphs presented are to be used in solving problems. Each of these design aids is prepared with upper limits. It's recommended that only application problems that fit under these limits are solved using these figures. Refer to qualified professionals for problems with parameters beyond the scope of the limits contained in the manual.

Every effort has been made to provide numbers in metric and imperial. Within the text, metric is followed by the imperial equivalent in parentheses, for example, 64 mm (2.5 in.). Metric and imperial tables are generally presented one after the other, with an M or an I in the title to indicate which it is. For example, Table 2.5-M Peak Flows from a Watershed (m^3/s), Runoff Curve Number 65 is followed by Table 2.5-I Peak Flows from a Watershed (ft^3/s), Runoff Curve Number 65. The design information sheets have two columns, one for metric and one for imperial.

This manual was first produced in 1986 through the efforts of the following committee: R.P. (Bob) Stone, P.Eng. (Chairman), Agricultural Engineer, Ontario Ministry of Agriculture and Food (OMAF), Brighton, Ontario; A.W. (Art) Bos, P.Eng., Senior Soil Conservation Advisor, OMAF, London, Ontario; H.W. (Hugh) Fraser, P.Eng., Agricultural Engineer, OMAF, Brantford, Ontario; B.D. (Brad) Glasman, P.Eng., Soil Conservation Engineer, Upper Thames River Conservation Authority, London, Ontario; D.R. (Don) Hilborn, P.Eng., Agricultural Engineer, OMAF, Cayuga, Ontario; J.W. (John) Johnson, P.Eng., Agricultural Engineer, OMAF, St. Thomas, Ontario; N.E. (Neil) Moore, P.Ag., Senior Soil Conservation Advisor, OMAF, Lindsay, Ontario; J.P. (Jim) Myslik, P.Eng., Agricultural Engineer, OMAF, Fergus, Ontario; G.M. (Glen) Slater, P.Eng., Agricultural Engineer, OMAF, Alexandria, Ontario; G.S. (Glenn) Stinson, C.E.T., Engineering Technician, OMAF, Brighton, Ontario; H.W. (Wayne) Wood, P.Eng., Drainage Coordinator, OMAF, Toronto, Ontario.

The manual was revised and updated in 2006 by the Upper Thames River Conservation Authority under the guidance of the following committees:

Project Committee (2006)

Hugh J. Smith, (Chair), Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA); Andrew Graham, Ontario Soil and Crop Improvement Association; Robert P. Stone, P. Eng., OMAFRA.

Technical Committee

Robert P. Stone, P. Eng., (Chair), OMAFRA; John Johnson, P. Eng., OMAFRA; Kevin McKague, P. Eng., OMAFRA; Jim Myslik, P. Eng., OMAFRA; Rebecca Shortt, P. Eng., OMAFRA; and Linda Cooper, OMAFRA.

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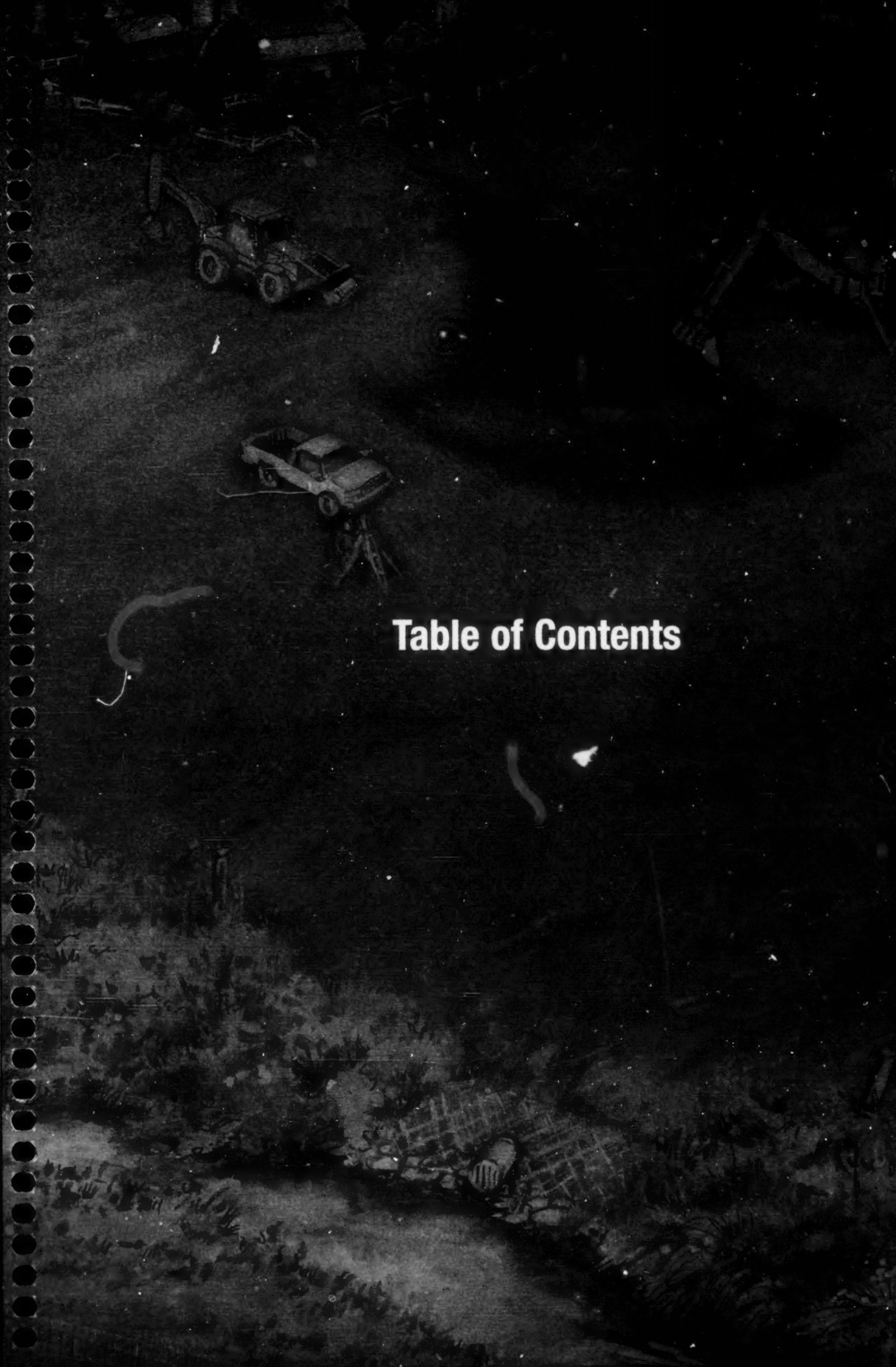

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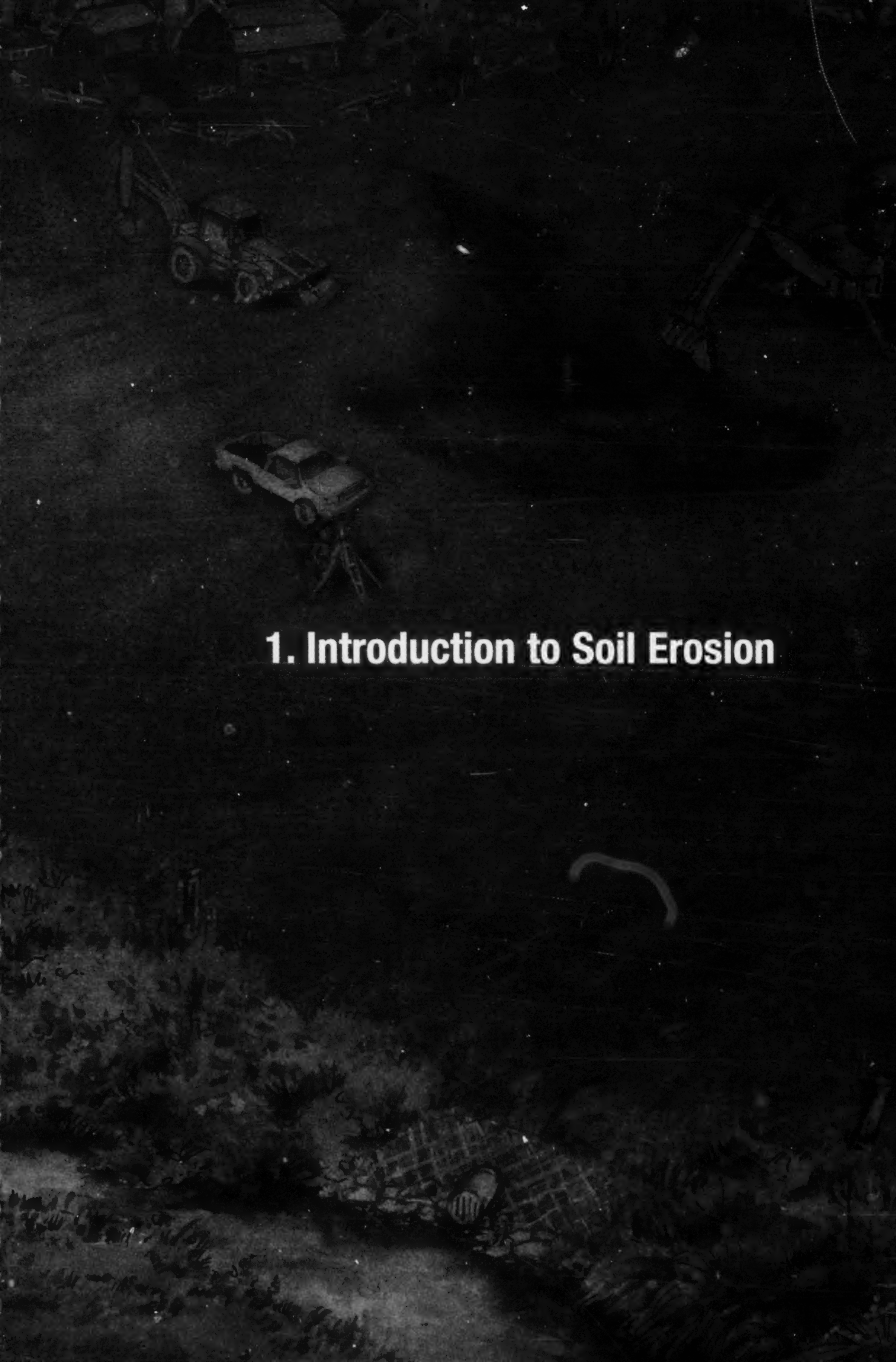


1. Introduction to Soil Erosion

1. Introduction to Soil Erosion

Soil erosion is a natural process that occurs at a relatively low rate on well protected soils. On Ontario farmland, however, soil erosion remains a concern. Soil that is blown or washed away is the most productive layer of soil on the land. Along with the soil, nutrients and possibly pesticides are also moved. These losses reduce yield potential. Eroded fields require large amounts of fertilizer to improve fertility and are harder to manage because of poor soil structure and low levels of organic matter. Soil that's carried away may plug drainage ditches and streams, reducing their capacity and costing millions of dollars in annual cleanouts.

Several factors influence soil erosion. Fortunately there are many conservation practices available to help solve the problem. Depending on the situation, one or several conservation practices may be needed. If conservation practices relate to crop and tillage management, consider involving a crop technology specialist. If the practice relates to structural projects, contact an agricultural engineer or contractor. Look into services available to landowners through local conservation authorities. To help defray the cost of specific conservation practices, look for cost-sharing programs related to structural projects or from other local agencies.

For more information on conservation practices, contact an Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) office or the Agricultural Information Contact Centre at 1-877-424-1300.

1.1 Wind Erosion

Wind blows unprotected dry, loose soil particles into drifts or carries them further downwind. Distance traveled depends on wind velocity and soil particle size, with very small particles traveling for many kilometres.

Soil nutrients, surface-applied chemicals and shallow-planted seeds can be carried along with the soil particles. The blasting effect of sand particles may also cause great damage, destroying young plants and injuring older plants. These injury sites allow disease organisms to invade the plant tissues.

Wind erosion is considered a problem on a small percentage of Ontario land – mainly sand and muck soils – but under the right conditions causes major losses of soil and property.

1.2 Water Erosion

Falling raindrops dislodge unprotected soil particles. If there is more rain than soil can absorb, the excess rain ponds or runs off. The runoff transports dislodged soil particles, moving them to another part of the field or off the field into ditches and streams.

Runoff causes three types of soil erosion – sheet, rill and gully. While gully erosion is the most dramatic and causes severe soil loss in a small area, sheet and rill erosion result in much more soil loss. Sheet and rill erosion are easily hidden with tillage and often not noticed. Sheet erosion removes uniform layers of soil, but is hard to see unless topsoil is measured. When looking for evidence of past erosion, look for knolls with light-coloured subsoil at the surface, or deeper than normal deposits of rich soil at the bottom of slopes. Rill erosion occurs when runoff is concentrated, but the damage is not severe enough to be classed as gully erosion since normal cultivation works down rills.

The capacity of soil to take in, or absorb rain is one of many factors affecting the amount of soil that's lost to water erosion. Soil structure is very important in influencing this infiltration capacity. Strong aggregates allow water to infiltrate, whereas weaker or poorly aggregated soil structures resist water penetration and result in more runoff. Infiltration capacity is also influenced by soil texture, organic matter content, the kind and amount of swelling clays, soil depth, and the presence of impervious soil layers such as compacted layers.

Water erosion also results from snow melt in late winter and early spring. Runoff increases if the ground is still frozen, preventing water from soaking in. As a result, waterways quickly erode into gullies with intense snow melt and spring rains. Streams and ditches run full, flushing out any sediment that may have been previously deposited.

Ditch bank erosion is also a result of the forces of water on the soil. The action of undercutting the banks with the resulting slumping of the tops of the banks can be dramatic and place heavy loads of sediment into some drainage systems. There are many reasons for ditch bank erosion and conservation practices are available to correct the problem.

1.2.1 Factors Affecting Soil Erosion by Water

Use the Universal Soil Loss Equation to estimate soil loss resulting from sheet and rill erosion.

$$A = R \times K \times LS \times C \times P$$

A – Estimated soil loss in tons/ac or tonnes/ha
R – Rainfall factor
K – Soil erodibility factor
LS – Length and slope gradient factor
C – Crop management factor
P – Erosion control practice

Rainfall or Precipitation – Brief, intense storms cause the most serious erosion. A fast spring melt after a winter with heavy snow cover has a similar effect on the top layer of soil.

Soil Type – The texture and physical condition of soil influences how well it resists erosion. Soils higher in organic matter absorb water more readily and runoff is reduced. Sandy soils are more resistant to water erosion than clay soils, but may be more susceptible to wind erosion. Table 1.1 outlines the general susceptibility of soil textures to erosion. Surface textures for an area of land are on soil maps. However, these maps may not be site specific, or erosion may have removed the topsoil, or the surface soil may be a blend of top and subsoils. Specific surface texture should be determined to identify the soil type involved. The top 15 cm (6 in.) of soil weighs about 2,240 tonnes/ha (1,000 tons/ac). The average soil is capable of maintaining itself at soil losses of less than 6.7 tonnes/ha (3 tons/ac). Water quality is influenced by losses greater than 2.24 tonnes/ha (1 ton/ac). A heavy thunderstorm may erode away 6 mm (¼ in.) of soil or more, which equates to 90 tonnes/ha (40 tons/ac) of soil lost that's almost unnoticeable.

Topography – Slope percentage and slope length are important factors. Plant very steep slopes with permanent forage crops or trees. Use alternating strips of forage and grain crops to reduce the length of the slope exposed to erosion. Field terraces reduce both the length and the slope.

Tile Drainage – Tile drains help remove excess gravitational water from soils. Tile drainage speeds drying and warming of the soil, allowing fields to be worked and planted earlier. Better timeliness of crop management usually equates to better crops and more residue to help cover or protect the soil. Soils that dry out faster are also able to absorb more moisture when it rains, reducing runoff and soil erosion. Naturally well-drained soils are able to absorb rain water, but tile drainage may be required along waterways to speed drying and reduce damage when crossing the waterway.

Tillage – Soil cover is traditionally tilled in the fall for most land scheduled to be planted to spring crops. Since tillage affects soil structure, a minimum number of passes is recommended – just enough to prepare a seed and root bed. It's possible to plant some fields with reduced or no tillage. Planters designed to plant into a field that hasn't been worked leaves most crop residue on the field to protect the soil from erosion. Tillage implements – such as mulch tillers and offset discs – are able to work the soil and leave about half of the crop residue on the surface. As a rough guide, each secondary trip with a tandem disc will bury about 40% of the residue left on the surface. A field cultivator will not incorporate as much of the original residue as the disc. The moldboard plow leaves almost no residue cover but may be the only choice of implement for soils that are imperfectly or poorly drained.

Crop Management – This is one of the main factors to consider in soil conservation. Permanent hay or well fertilized pasture provides ideal protection in highly erosion-prone areas. Crops planted on the contour or in strips can break up the length of the slope and reduce erosion.

Crop rotation provides:

- better timing for tillage, planting and harvesting
- better weed, insect and disease control
- better soil structure

Crop cover – or dead residue – protects soil from the force of raindrops, wind and protects soil over the winter. Examples include winter cereals, cereals underseeded to forages for plow down in the spring or residue left on the surface. If additional protection is required, strawy manure or straw that's been crimped into soil will help. In all cases, do a soil test to determine fertilizer requirements to produce a healthy, vigorous crop.

Table 1.1. General Susceptibility of Soil Textures to Erosion

Surface Soil Texture	Relative Susceptibility to Water Erosion*
Very fine sand	Very high (very erodible)
Loamy very fine sand Silt loam Very fine sandy loam Silty clay loam	High (erodible)
Clay loam Loam Silty clay Clay Sandy clay loam Fine sand Heavy clay	Medium (moderately erodible)
Sandy loam Loamy fine sand Fine sand Coarse sandy loam	Low (slightly erodible)
Loamy sand Sand	Very low (erosion resistant)

*Based on calculated soil erodibilities for 1,600 surface samples taken in southern Ontario and on inherent, soil erodibility classes provided by the Ministry of Transportation.

1.2.2 Structural Controls

While tillage and cropping programs help reduce soil erosion, there are situations – primarily involving natural drainageways or swales – that require structural controls to further reduce soil erosion where concentrated runoff occurs. Surface drainage via grassed waterways or ditches is necessary in areas of water concentration and is often supplemented by tile drainage. Some projects may involve large watersheds, provided that proper outlets are available and landowners are willing to co-operate. Other projects, such as a municipal drain, may fall under the *Drainage Act, R.S.O. 1990.*

Grassed Waterway – A broad shallow channel constructed with a slight grade to slowly carry water down the slope. Located along a natural flow path, a grassed waterway is planted with grass and/or legumes to slow the flow and protect the channel.

Open Ditch – An excavated narrow, deep channel. The banks and field buffer strips at the bank tops are seeded. Rock may be placed to protect the interior bank slopes from undercutting, particularly on corners. Bank sides are sloped to be stable for the soil conditions. Interceptor tile running parallel to the ditch may be required if ground water is seeping and undermining the bank. Tile outfall protection is required.

Grade Control Structures – A type of drop structure required in water channels with an abrupt change in grade, or if the grade needs to be reduced to prevent soil erosion problems. An important location is where a grassed waterway enters an open ditch. Gabion basket and log type structures are options for providing grade control protection.

Berms or Runoff Diversions – Soil is piled and used to direct water into a grassed waterway, open ditch or drop structure. These structures should be vegetated.

Terracing – Land grading to pond water for controlled release.

Water and Sediment Control Basins – Small water detention basins used to pond water, usually for up to 24 hours, to reduce runoff and erosion. Ponded water drains from the basin by a drop pipe inlet, usually into a tile drainage system.

Field Terraces – Land is graded to flat terraces to reduce runoff from long sloping fields. Diversions, grassed waterways and drop structures may also be involved.

Sediment Basins – Excavated, diked or possibly dammed basins used as a last resort to intercept and trap sediment before it enters an environmentally-sensitive area, stream, ditch or other body of water. Minimum retention period is 24 hours.

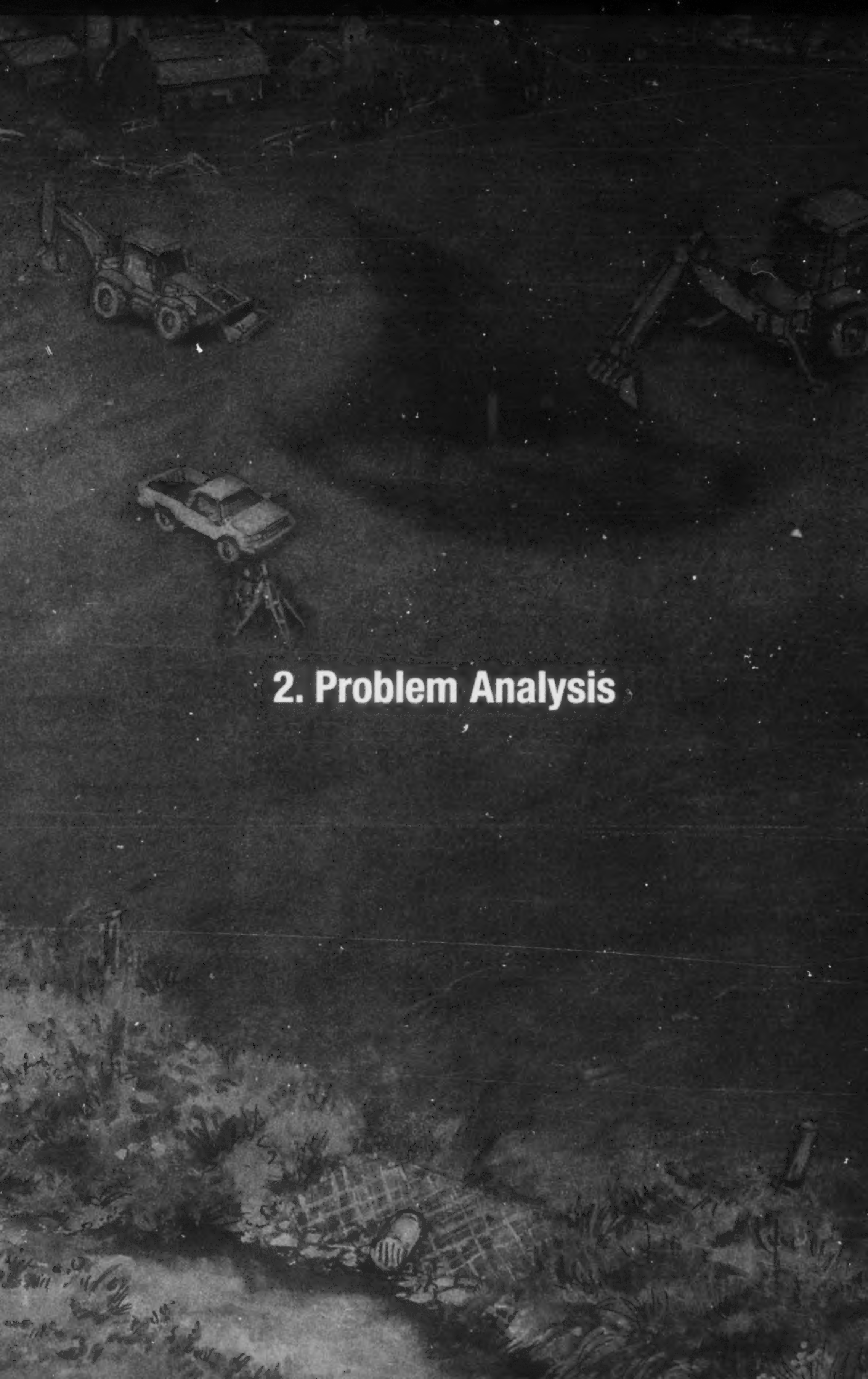
Chute Spillways – A type of drop structure usually constructed with rock to carry water down a natural or shaped incline.

Catch Basin – A drop pipe inlet used to drop surface water into a tile drainage system. Best location is at a point source such as a road culvert or land constriction.

Drop Pipe Inlets – A type of drop structure used to drop surface water at an abrupt change of grade, for example into drainage ditches, streams and gullies.

Fencing and Low Level Crossing – Livestock have a detrimental effect on water quality if allowed to access watercourses. They also destroy grass cover on the ditch bank, leaving the bank susceptible to erosion. Where livestock must receive water from the stream, install a pumping system to move water away from the stream to an environmentally-safe area. Nose pumps or solar-powered pumps are options if a power supply is not available nearby. Livestock often cross a waterway to get to pasture on the other side of the stream. When this occurs, install a low flow, mid-level stream crossing with culverts, together with a fencing system to provide a restricted location for crossing. An existing stream riffle may be suitable in some cases.

Tile Outfalls – Outfalls (outlets) are the most important part of the tile drainage system. Keep them to a minimum number after they're properly constructed and protected.



2. Problem Analysis

2. Problem Analysis

2.1 Site Visit – What to Look for

The first questions to answer are: Does your client have an erosion problem? Do they want it controlled? How and where can the problem be controlled?

In some cases, work is required at the erosion site. In other cases, the solution needs to be located elsewhere in the watershed. For example, don't design and build a structure if siltation from erosion upstream will completely fill the water storage of the structure within a year.

This manual covers structural solutions and doesn't discuss other solutions such as minimum tillage or crop rotation changes. These alternatives are often as important – and sometimes more – than structural solutions.

For a structural solution, consider the following.

Soil Type – Soil type is required to determine peak flows and often to design the base of the structure. The type of subsoil greatly affects overall permeability. Use an auger or other probe to assess this factor.

Topography – Topography or elevation changes over the watershed affect peak flows and the type and design of structure used. Determine slope using topographic maps or simple handheld indicators. If the area is extremely flat, or more precise calculations are needed, a site survey will be required.

Crops Used and Farming Practices – The type of crop and crop rotation have a dramatic affect on the peak flow expected at one point. Be sure to incorporate the worst case crop or crop rotation into the design. For example, a drop structure designed to handle the peak flow from 8 ha (20 ac) of permanent pasture may fail if the landowner decides to fall plow and plant corn the next spring. Farming practices have a bearing on the structural design used.

Cropping a very large acreage requires a fail proof structure, compared to a farm with a smaller, more specialized land base which has a higher maintenance structure. An erosion control structure must work with the existing farming system. For example, a grassed waterway fits very well with an operation that has machinery and uses for hay.

Watershed Size – Watershed size is a key factor in the peak flow expected and the type of erosion control structure or structures proposed. See Section 2.2, Determining the Size of a Watershed.

Legal Aspects – When initiating a design, always consider the legal aspects. There are instances where improving the erosion resistance of a watercourse may initiate liability problems with a landowner up or downstream. Any work in or around a municipal drain requires municipal approval. See Appendix C for laws which may affect an erosion control plan.

Available Materials – Many farms, especially in the tobacco belt areas, have high quality sand fill readily available. Take this resource into account when determining the type and layout of a design. Farmers often want to use existing field stone or concrete rubble in erosion control structures. Be sure all available materials are adequate for the design.

Information Sheet – During the site visit, complete the Structural Erosion Control Information Sheet with the above details.

Structural Erosion Control Information Sheet

1. Landowner

Name	
Address	
Phone	E-mail

2. Contractor

Name	
Address	
Phone	E-mail

3. Location of Erosion Problem

Lot	Concession
Municipality	County/Region

4. Erosion Problem (include sketch on page 10)

Description
Proposed Control

5. Watershed Characteristics

Size ________ ha	________ ac
Soil Type	

Watershed cover

Crops grown ________ ha	________ ac
- straight row ________ ha	________ ac
- contoured ________ ha	________ ac
- terraced ________ ha	________ ac
Woods ________ ha	________ ac
Pasture ________ ha	________ ac

Watershed hydrologic condition

Poor	Fair	Good

Watershed slopes

Flat (<5%)	Rolling (5% to 10%)	Hilly (>10%)

6. Erosion Problem Area

Soil type	
Crops – current	
Crops – rotation with	

7. Buried Utilities, Objects, etc.

8. Other Site Information

9. Refer to the following information sheets to complete solution to problem.
- work sheet to determine peak flow rate from an agricultural watershed
- grassed waterway design information sheet
- rock chute design information sheet
- drop pipe inlet design information sheet
- grade control structure design information sheet
- water and sediment control basin (WASCoB) design information sheet
- tile/surface water inlet design information sheet

10. See Figure 2.1, sketch and include:
- north direction (at top of page)
- roads, buildings, etc., indicating any effect they have on flow into or out of watershed
- approximate field boundaries
- approximate watershed boundary
- exact location of erosion problem
- location of proposed structural solution

Note: Include a survey showing field elevations for the erosion problem area where necessary for design, e.g. grassed waterway, drop structures.

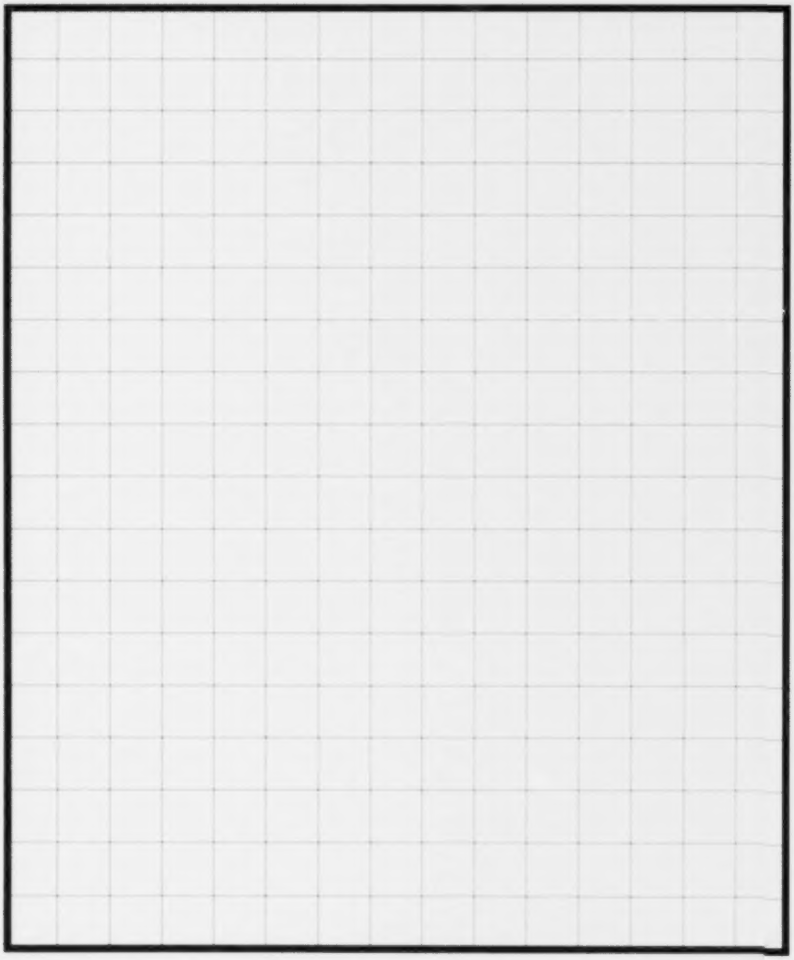


Figure 2.1. Location of Erosion Problem Area

2.2 Determining the Size of a Watershed

Determine the contributing watershed size as accurately as possible when designing erosion control structures. Use a combination of maps, aerial photographs, and in-field measurements and observations, as well as input from the landowner. Watershed boundaries are relatively easy to determine. Identifying boundaries is more challenging, however, where lands are fairly level, bush lots are involved or watershed boundaries go beyond the property boundary making access difficult.

The best way to determine watershed size involves using planning aids and contours lines to determine watershed boundaries.

2.2.1 Planning Aids

This section outlines planning aids to consider when designing erosion control structures.

National Topographic Surveys

Topographic maps have contours drawn at 10 m intervals – 25 ft and 50 ft intervals may also be available. Use maps to determine the general slope in any area, the size of a drainage basin or the location of possible outlets. Forested areas and landmarks such as bridges, roads, railways and buildings are shown. Geodetic bench marks are shown where they have been established. The map scale is 1:50000. These maps are available from:

Canada Map Office
Centre for Topographic Information
Natural Resources Canada
615 Booth Street, Room 180
Ottawa, Ontario Canada K1A 0E9
Telephone: 1-800-465-6277
Fax: 613-947-7948
E-mail: topo.maps@NRCan.gc.ca
http://maps.nrcan.gc.ca/index_e.php

Ontario Base Mapping Program

In limited areas of Ontario, maps have been produced under the Ontario Base Mapping Program. These maps are made to a high standard of accuracy and are produced on a 1:10000 scale with 5 m contours for southern Ontario. Maps for northern Ontario are available in a 1:20000 scale with 10 m contours. The larger scale on these maps, and closely spaced contour lines make these maps a good source for establishing watershed areas, low lying areas, outlets, grade, etc. Maps are available on-line at *http://themnrstore.mnr.gov.on.ca*

Order Ontario Base Maps via fax from Natural Resources Information Centre at 705-755-1677. Include township, lot and concession number of the desired area, or a clear description of boundaries of the area, as well as your name and phone number. For further information, call 1-800-667-1940.

Township and County Maps

Municipalities often have township maps showing all roads, lots and concessions, natural watercourses and all outlet ditches constructed under provincial statutes up to the date of drawing. Some municipalities include the watersheds of the drainage reports. These maps are useful to contractors and engineers in helping establish outlets and watershed boundaries. Copies of township maps and drainage reports may be viewed at the municipal office and, in some cases, through the local website.

Soils Reports and OMAFRA Mapping

Soil maps provide general information on the soil type, topography, contours, roads, lots, concessions, township boundaries and surface stoniness. These maps are used to determine soil type, which is useful when considering the erodibility of the soil. Most counties in Ontario have soil surveys and maps. Visit the OMAFRA website at *www.ontario.ca/omafra* for a list of available soil maps and reports. For Agriculture and Agri-Food Canada, visit *www.sis.agr.gc.ca/cansis/publications/*

Aerial Photographs

An aerial photograph captures the view of a tract of land from above. All ground features are shown including buildings, fence lines, ground cover and roads. Aerial photographs help determine existing drainage patterns, which may assist the locating of a grassed waterway, open ditch, etc. They may be obtained from the local conservation authority or municipality.

Other Resources

Municipal or regional planning groups and conservation authorities may have maps for zoning by-laws, or soil and water resources. Being familiar with local plans protects a contractor's business from liability if land is zoned for other than agricultural production.

Plans showing the location of buried cables, oil and gas pipelines, and municipal below grade installations are available from the respective authorities.

Topographic maps are prepared for tile drainage purposes, and are useful in designing erosion control projects. Contact an OMAFRA agricultural engineer for access to any plans drawn for this purpose.

Other mapping-related resources available from OMAFRA include:

Artificial Drainage Systems Maps – Indicate the locations of municipal tile drainage systems installed by licensed contractors since 1983. Some maps are more up to date than others. Maps are available in white print format at a scale of 1:25000, size approximately 30"x 42". Order through the OMAFRA website at *www.ontario.ca/omafra*

Agricultural Land Use Systems Maps – Indicate the variation in land use systems and non-use systems. Maps are by township. Available in white print format at a scale of 1:50000, size approximately 30"x 24".

Canada Land Inventory, Agricultural Capability Rating Maps – Indicates the breakdown of Ontario's agricultural land into seven capability classes, and is overlaid on 1:50000 National Topographic System (NTS). Available in white print format at a scale of 1:50000 for areas of significant agricultural activity in northern and southern Ontario. Size is approximately 30"x 36".

To obtain information and order copies of any of the maps listed above, contact ServiceOntario at 1-888-466-2372 within Ontario or 519-826-3700 outside Ontario.

Purchase soils survey reports, soil maps and agricultural capability maps through the OMAFRA website at *www.ontario.ca/omafra* or by calling 1-888-466-2372 (within Ontario or 519-826-3100 outside Ontario). Updated agricultural capability rating information is available in re-surveyed and updated soils reports for the following municipalities: Ottawa, Ottawa Urban Fringe, Peterborough, Lanark, Niagara, Kent, Elgin, Haldimand-Norfolk, Brant, Waterloo and Middlesex.

2.2.2 Using Contour Lines to Determine Slope and Watershed Boundaries

A watershed is generally the total land area that drains to a particular lake, river or stream. When discussing erosion control structures, the watershed may be defined as the land area that drains toward a specific point such as a field, gully or intermittent stream. The area can be large or small.

Watershed basin size is a very important factor used to determine peak flows, which in turn are used for sizing erosion control structures such as grassed waterways and drop structures. This makes it very important to establish the watershed boundary as accurately as possible. Topographic maps are used to outline watershed boundaries and determine their area. Topographic maps show elevations and the shape of the terrain (i.e. hills, peaks and valleys) using raised-relief, shaded-relief and most often, contour lines.

Contour lines on topographic maps help locate watershed boundaries and the slope of the area within the basin. Determine what the contours represent, how they are drawn, and how to use them. When an area of land is surveyed, these contours indicate the slope of the land and the general terrain features.

When a survey is completed for a tract of land, elevations are taken and plotted to scale on a sheet of paper. The resulting two dimensional scaled drawing of a field includes a lot of elevations. The ground elevations provide the third dimension – the vertical component – indicating whether the ground is rising or falling and in what pattern. Using elevations alone is very difficult, and contours provide an easy-to-view description of what the ground surface looks like regarding slope.

The most basic principle of a contour line is that it's a line joining points of equal elevations (heights). Contour lines have a single, even numbered elevation assigned to them. Any point on that line has the same elevation (height) of land. Contour lines are shown as solid lines, dashed lines or a combination of both.

Rules for Drawing Contour Lines

- Contour lines connect points of equal elevation.
- Contour lines never cross each other.
- Every contour line meets itself either on the map or outside of the surveyed area.
- A contour line never splits into two contour lines.
- Contour lines must be drawn so that the ground higher than the contour line is always on the same side of the contour line.

Interpolating Contours

When drawing a contour line between two elevation points, interpolation may be required.

Contour lines are usually whole number elevations in increments of 1, 3, 5 or 10 m (1, 5, 10 or 25 ft) and most elevation points are not even numbers. Find even numbered elevation points by using the existing data. Then connect these points using the rules of contouring mentioned above.

There are various methods to draw contours. Modern methods use computers, but very often are done by hand. The hand method is very technical, using mathematical and scaling rules for determining the points very accurately. This method can also be done by hand with a more practical method of estimating the location of the additional data points using good judgement and basic mathematical skills. The level of accuracy required often determines which method is used.

Method 1 – Mathematical Method

In Example 1 (Figure 2.2), the known set of data points is the 55 m and 65 m elevation points and the 50 m distance between them. In order to draw the 60 m elevation point, determine the distance from the 55 m elevation point to the 60 m elevation point.

The mathematical equation is:

$$X = \frac{(Y - Ya)(Xb - Xa)}{(Yb - Ya)}$$

Where: X = distance from lower (known) contour point to unknown contour point
Y = contour elevation at unknown point
Xb – Xa = distance between known contour points
Yb = contour elevation at higher known point
Ya = contour elevation at lower known point

Therefore:

$$X = \frac{(60\text{-}55)(50)}{(65\text{-}55)}$$

$$X = \frac{(5)(50)}{(10)}$$

$$X = \frac{250}{10}$$

$$X = 25 \text{ m}$$

The 60 m elevation point goes 25 m away from the 55 m elevation point.

For Example 2 (Figure 2.3), the known set of data points is the 55 m and 70 m elevation points and the 60 m distance between them. In order to draw the 60 m elevation point, determine the distance from the 55 m elevation point to the 60 m elevation point.

$$X = \frac{(60\text{-}55)(60)}{(70\text{-}55)}$$

$$X = \frac{(5)(60)}{(15)}$$

$$X = \frac{300}{15}$$

$$X = 20 \text{ m}$$

The 60 m elevation point goes 20 m away from the 55 m elevation point.

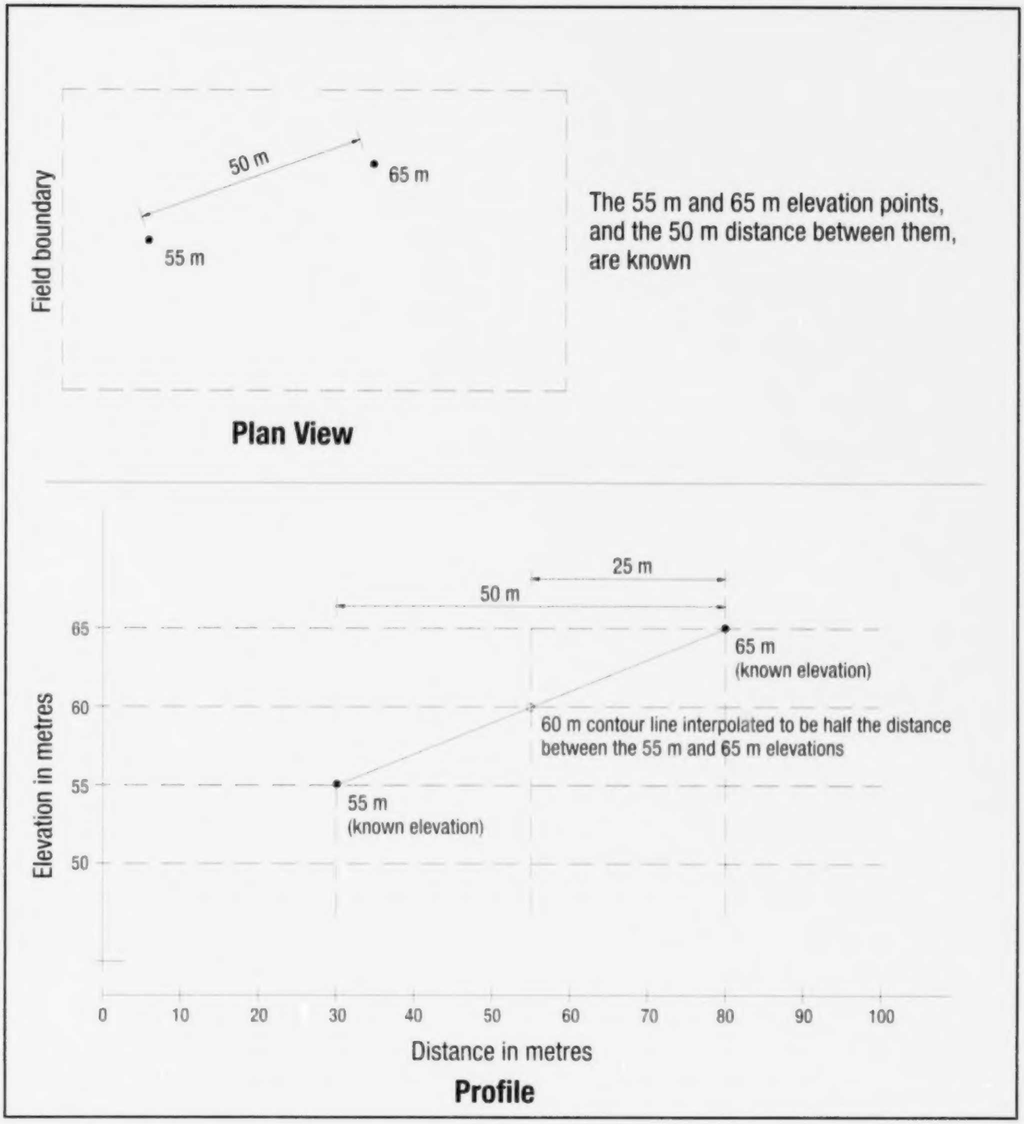


Figure 2.2. Principle of Interpolating Contours – Example 1

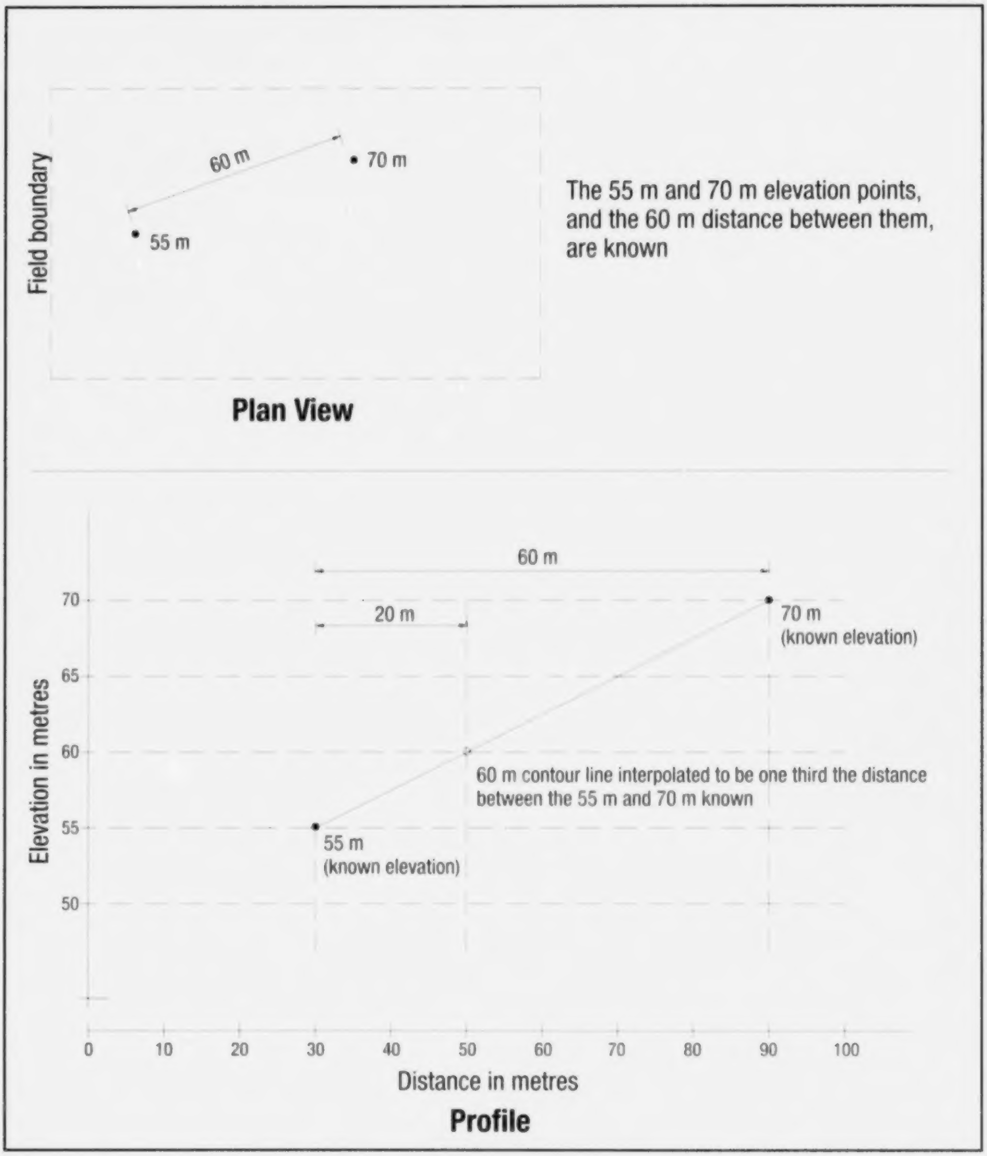


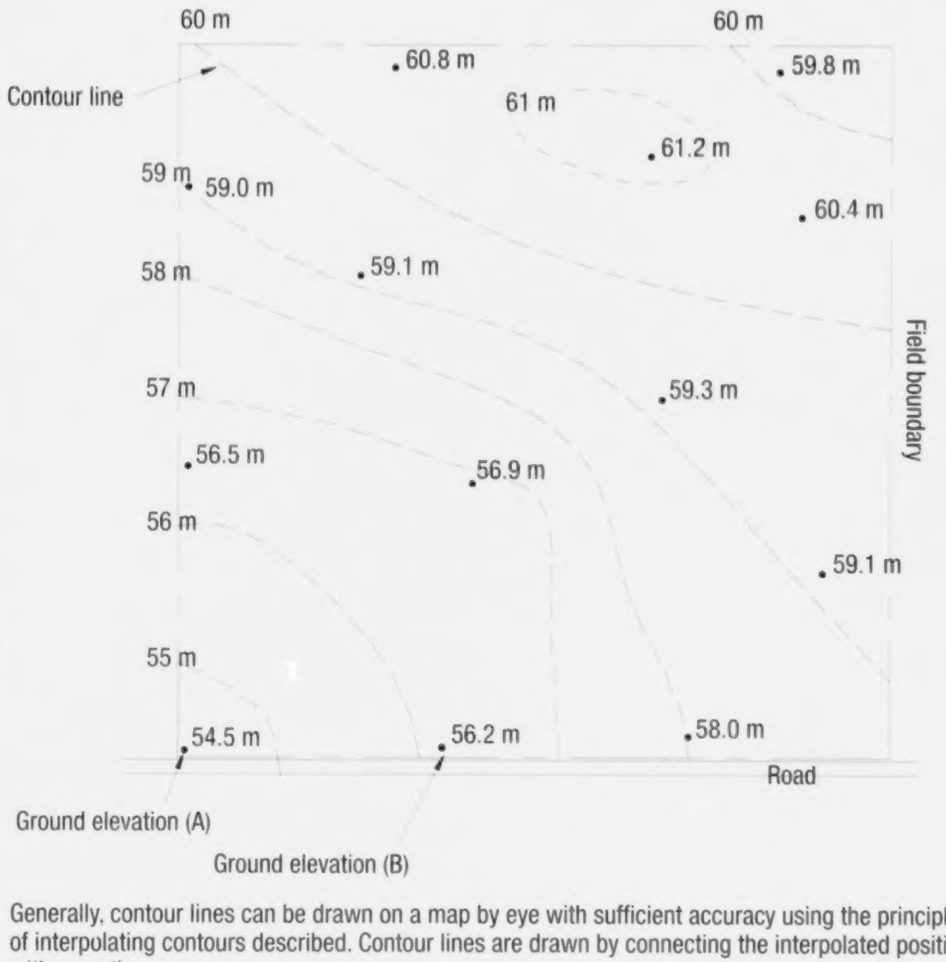
Figure 2.3. Principle of Interpolating Contours – Example 2

Method 2 – Practical Method

Using the same Example 1 and looking at the plan view in Figure 2.2, there are two point elevations of 65 m and 55 m. The objective is to draw contour lines in 5 m intervals and find the point where the elevation is 60 m in order to be able to draw the 60 m contour line. In this case, it's easy to find since the desired point elevation of 60 m is 5 m less than the 65 m point elevation and 5 m higher than the 55 m point elevation. It's assumed there is one constant uniform slope between the two point elevations, so the 60 m elevation is located halfway between the two points. The point is located horizontally in the same proportions as it is positioned vertically between the two known elevations. This process is carried out for all the appropriate adjacent pairs of points. Once all the 60 m elevation points are identified, they are connected following the previously stated rules of contouring and a contour line of one elevation is drawn. This process can be repeated for any desired contour elevation.

In Example 2, and referring to the plan view in Figure 2.3, the task is to find the 60 m contour point once again. In this case, the point is 10 m lower than 70 m elevation and 5 m higher than 55 m elevation. The proportioning or ratio here is 10:5 or simplified is 2:1. This means the 60 m elevation is two times further away from the 70 m elevation than it is from the 55 m elevation. It's a matter of developing a technique to proportion the location of the particular elevation desired.

Using the above principles means all necessary points can be interpolated and contour lines drawn as shown when looking at a more complete topographic survey with a number of elevations, such as in Figure 2.4.



Generally, contour lines can be drawn on a map by eye with sufficient accuracy using the principle of interpolating contours described. Contour lines are drawn by connecting the interpolated positions with smooth curves.

Figure 2.4. Plot Plan Showing Interpolation of Contour Lines

A completed contour map provides a considerable amount of information.

- Evenly spaced contour lines indicate a uniform grade or slope.
- Widely spaced contour lines show a flatter grade.
- Closely spaced lines indicate a steeper grade.
- High and low spots can be quickly identified on the map. Closed contour lines surrounded by other closed contour lines indicate either a hill or a depression.

When a map is correctly contoured, all the area on one side of the contour line will be either at a greater or lesser elevation than the elevation of the contour line.

Contour intervals (difference in elevation between lines) and units (metric or imperial) vary based on the mapping system used, or can be determined in the field. Topographic maps prepared by contractors for erosion control or drainage purposes generally have very detailed contour information drawn at 1 ft intervals. Contour lines may be dotted or solid lines on maps used for design, but dotted lines are preferred on plans prepared by contractors.

Contours and Water Flow

How do contours relate to water flow? Here are a few rules to follow:

- Surface water runoff flows perpendicular to contours.
- When water runs downhill, it flows into progressively larger watercourses and eventually into a lake or other water body. Water often flows as a sheet, then concentrates into swales or drainageways and then into an intermittent watercourse. Eventually a permanent stream develops when the watershed size is large enough.
- Successively higher and higher contour lines cross the watercourse (Figure 2.5) when going upstream along a watercourse. Contour lines always point upstream because the bed of the drainageway or watercourse rises as it goes upstream.
- The highest point upstream is the head of the watershed, beyond which land slopes to another watershed.
- At each point along the watercourse, land slopes up on each side to some high point and then down into another watershed. Joining all these high points creates a watershed boundary. These high points are generally hill tops, ridge lines or saddles.
- Any point on a watercourse can be used to define a watershed.

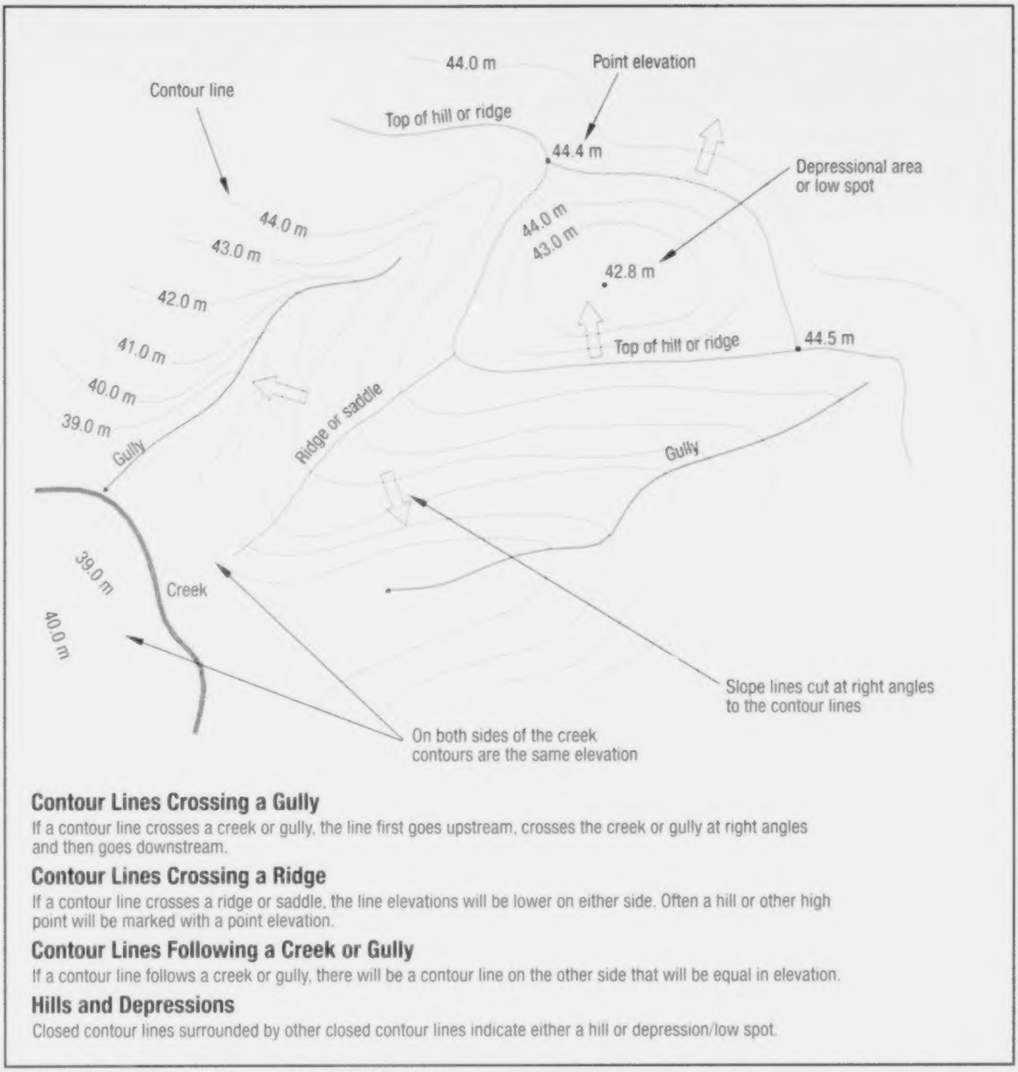


Figure 2.5. Interpreting Contour Lines

Delineating a Watershed

The following method and the accompanying examples (Figures 2.6 to 2.10) will assist in locating and connecting the high points around a watershed on a topographical map.

1. Locate the point where peak flow is to be determined (Figure 2.6).
2. Identify overland runoff patterns from mapping. Remember, a contour line crossing a natural drainageway (creek or gully) goes upstream, crosses the drainageway at right angles, then goes downstream (Figure 2.7).
3. Indicate the high points along the watercourse, working upstream (Figure 2.8a) towards the headwaters of the watershed and then down (Figure 2.8b) the other side.
4. Beginning at the outlet, connect the high points along one side of the watercourse (Figure 2.9a). This line always crosses the contours at right angles (perpendicular to each contour line it crosses). Continue the line until it passes around the head of the watershed and down the opposite side of the watercourse. Eventually, the line arrives back at the outlet location (Figure 2.9b).

At this point, the watershed boundary is delineated or outlined (Figure 2.10). All surface water runoff from rain falling anywhere in this area flows to the outlet.

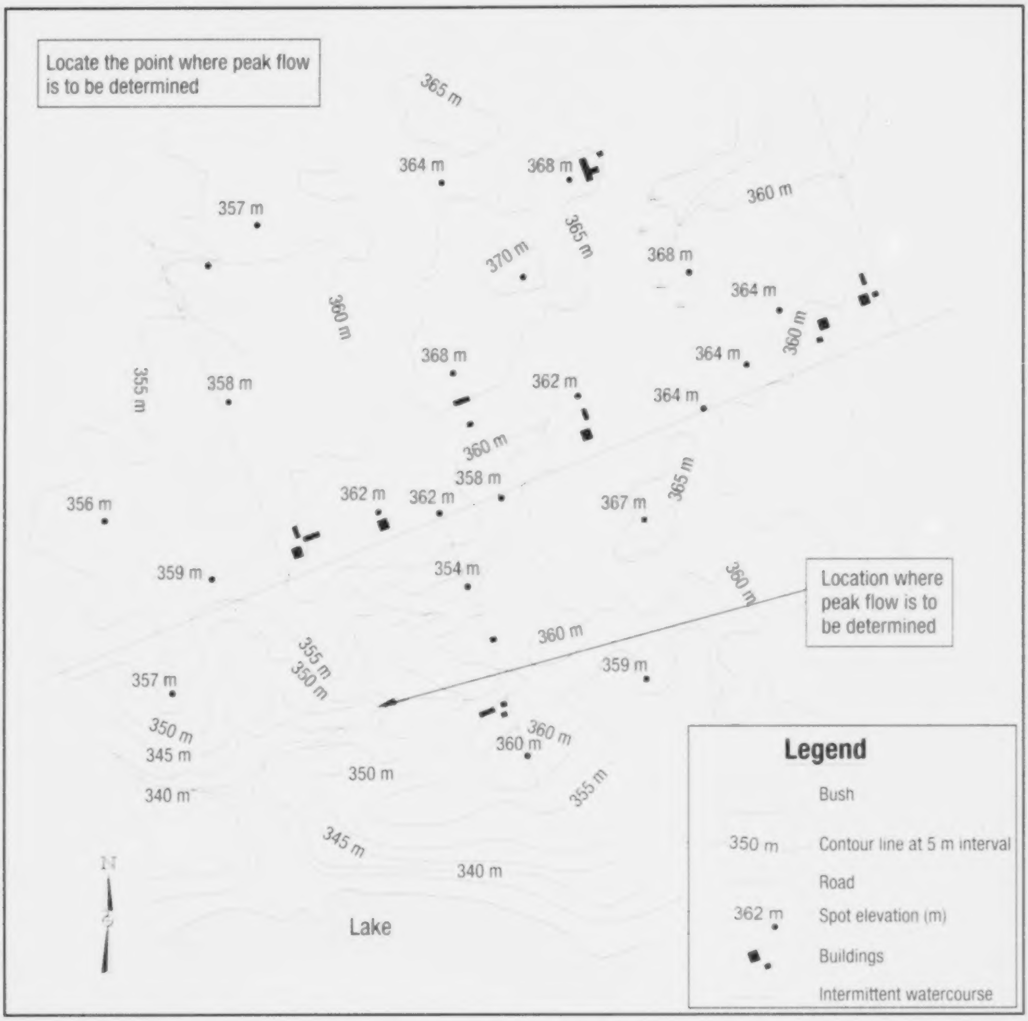


Figure 2.6. Delineating a Watershed Using a Contour Map – Identify Peak Flow Location

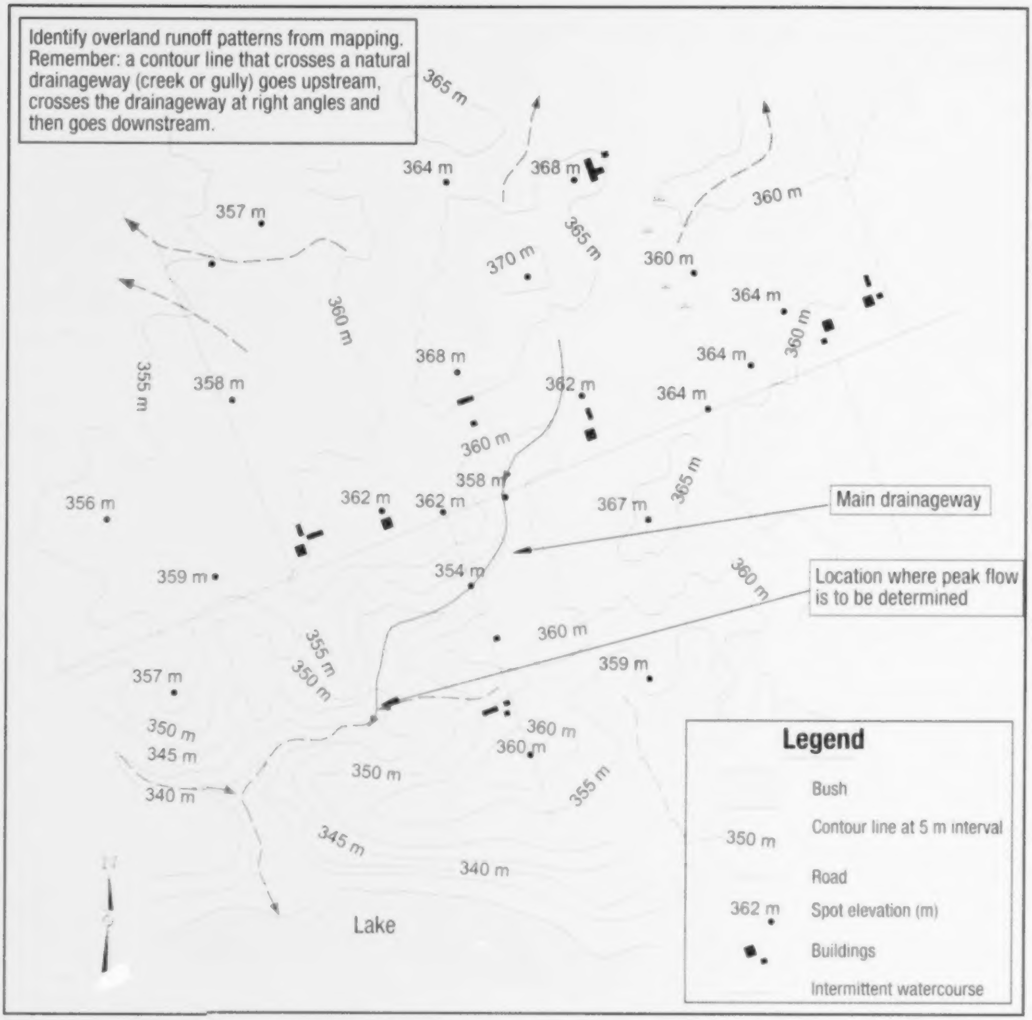


Figure 2.7. Delineating a Watershed Using a Contour Map – Identify Runoff Patterns

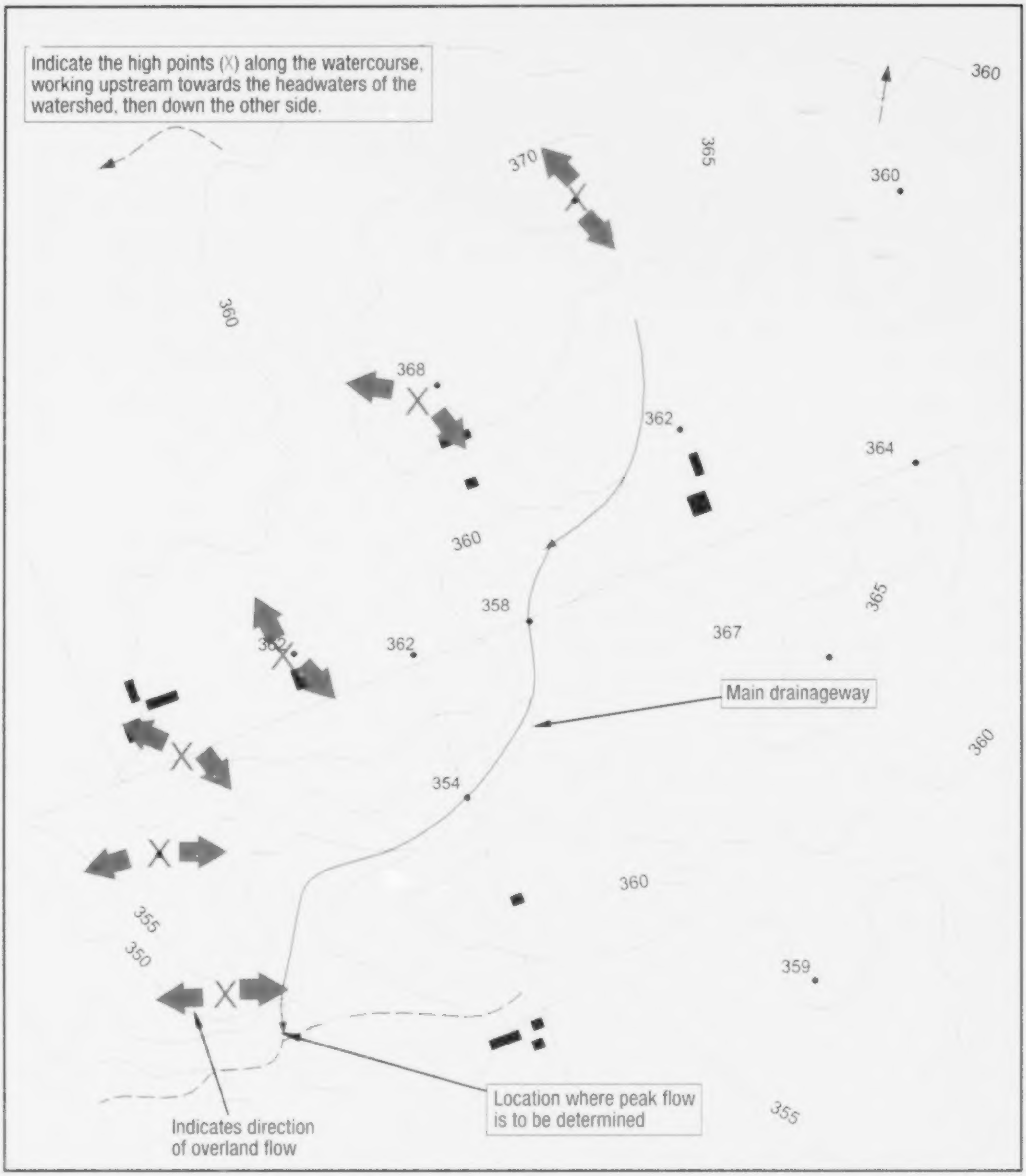


Figure 2.8a. Delineating a Watershed Using a Contour Map – Identify High Points

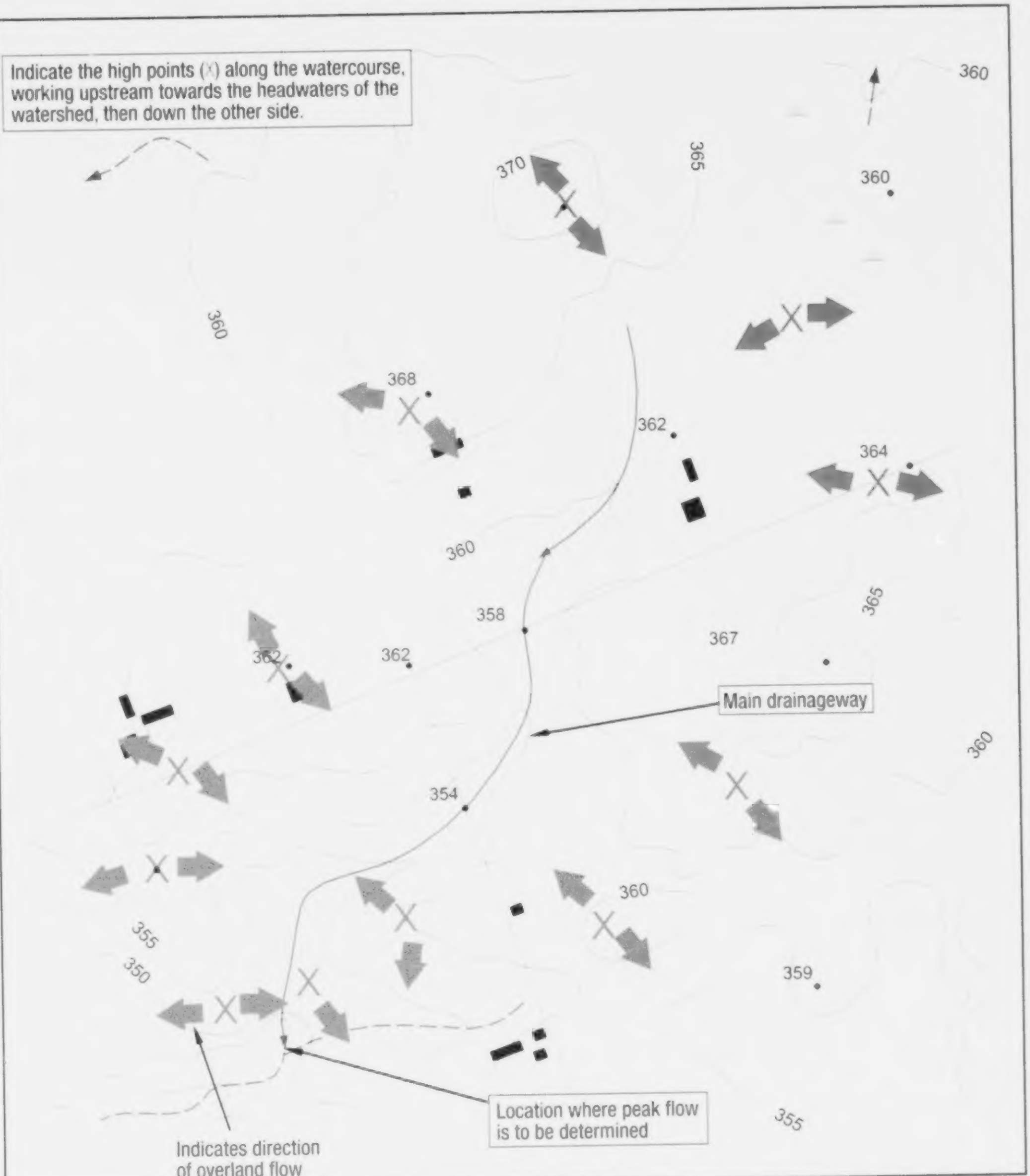


Figure 2.8b. Delineating a Watershed Using a Contour Map – Identify High Points

Figure 2.8a. Delineating a Watershed Using a Contour Map – Identify high points

Figure 2.8: Delineating a Watershed Using a Contour Map – Identify High Points

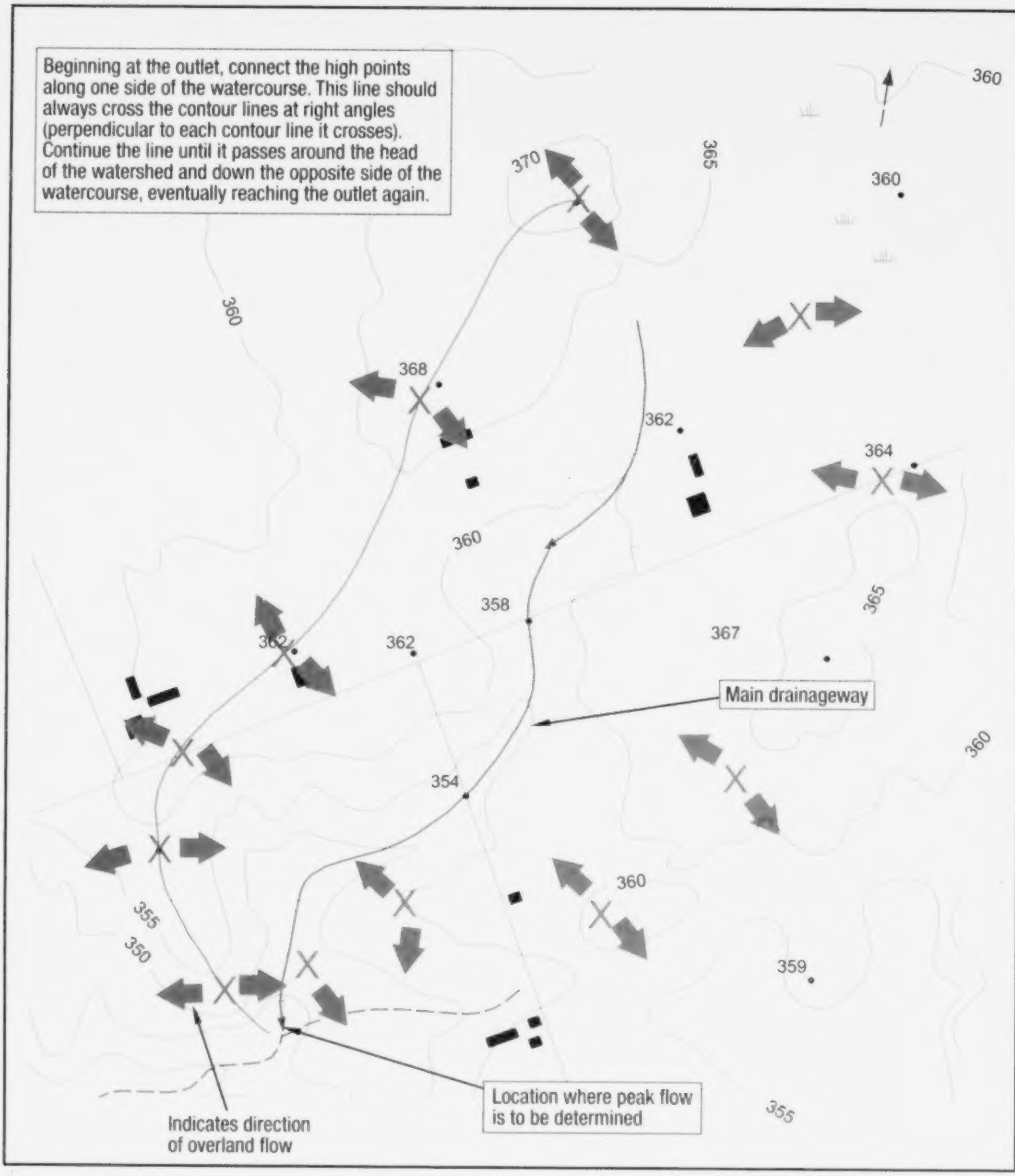


Figure 2.9a. Delineating a Watershed Using a Contour Map – Connect High Points

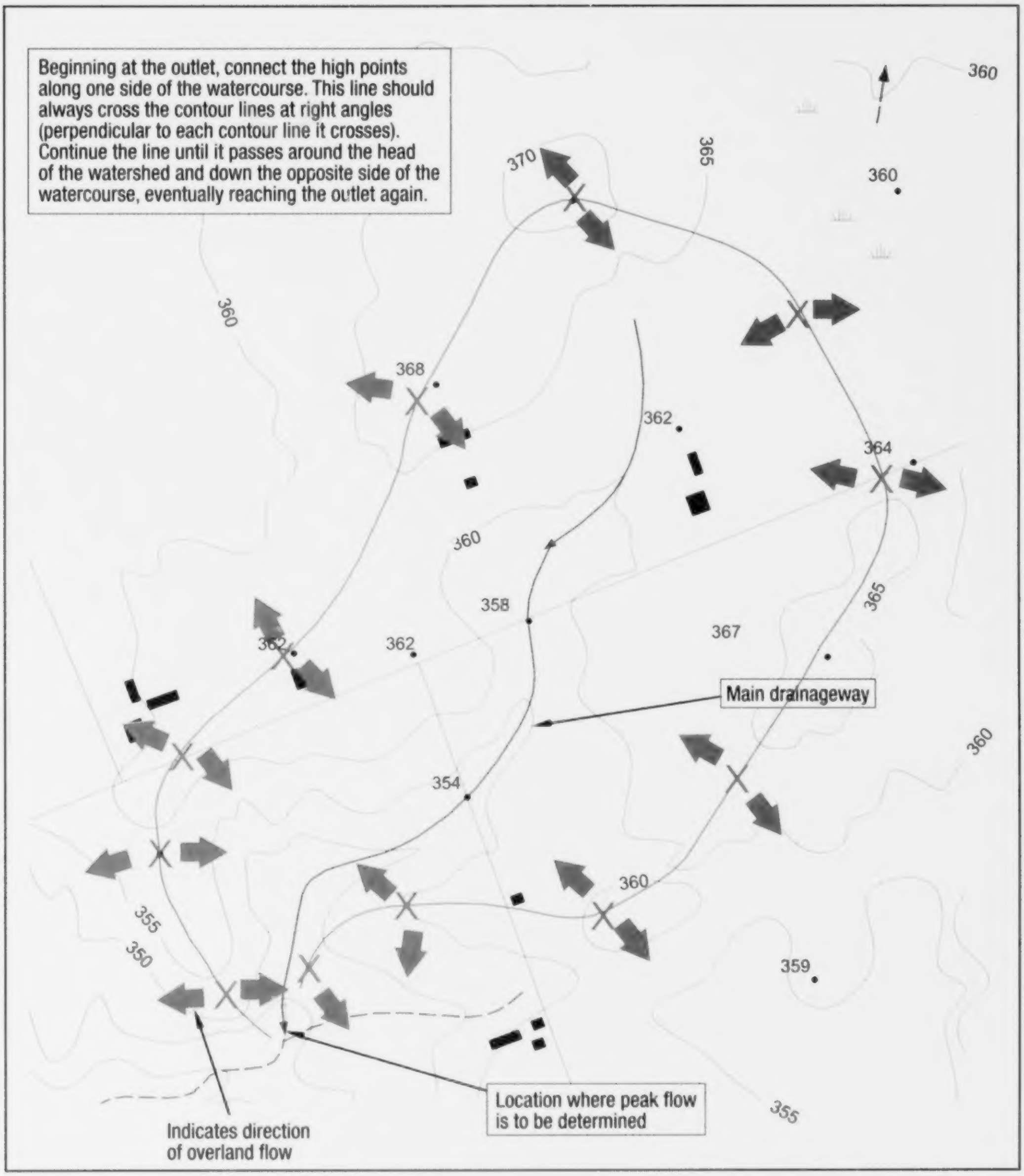


Figure 2.9b. Delineating a Watershed Using a Contour Map – Connect High Points

Figure 2.6a: Delineating a Watershed Using a Contour Map – Connect High Points

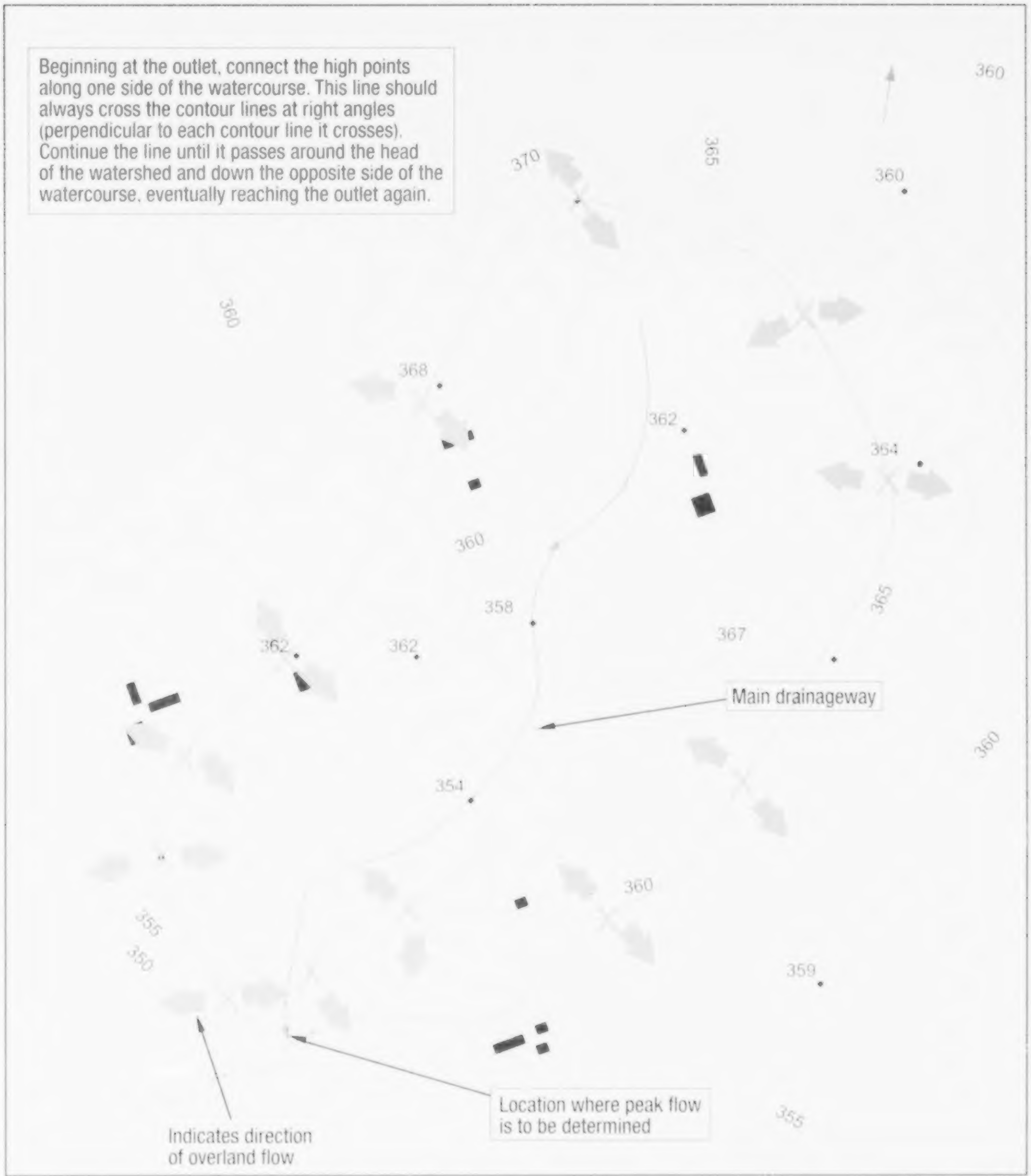


Figure 2.9b Delineating a Watershed Using a Contour Map – Connect High Points

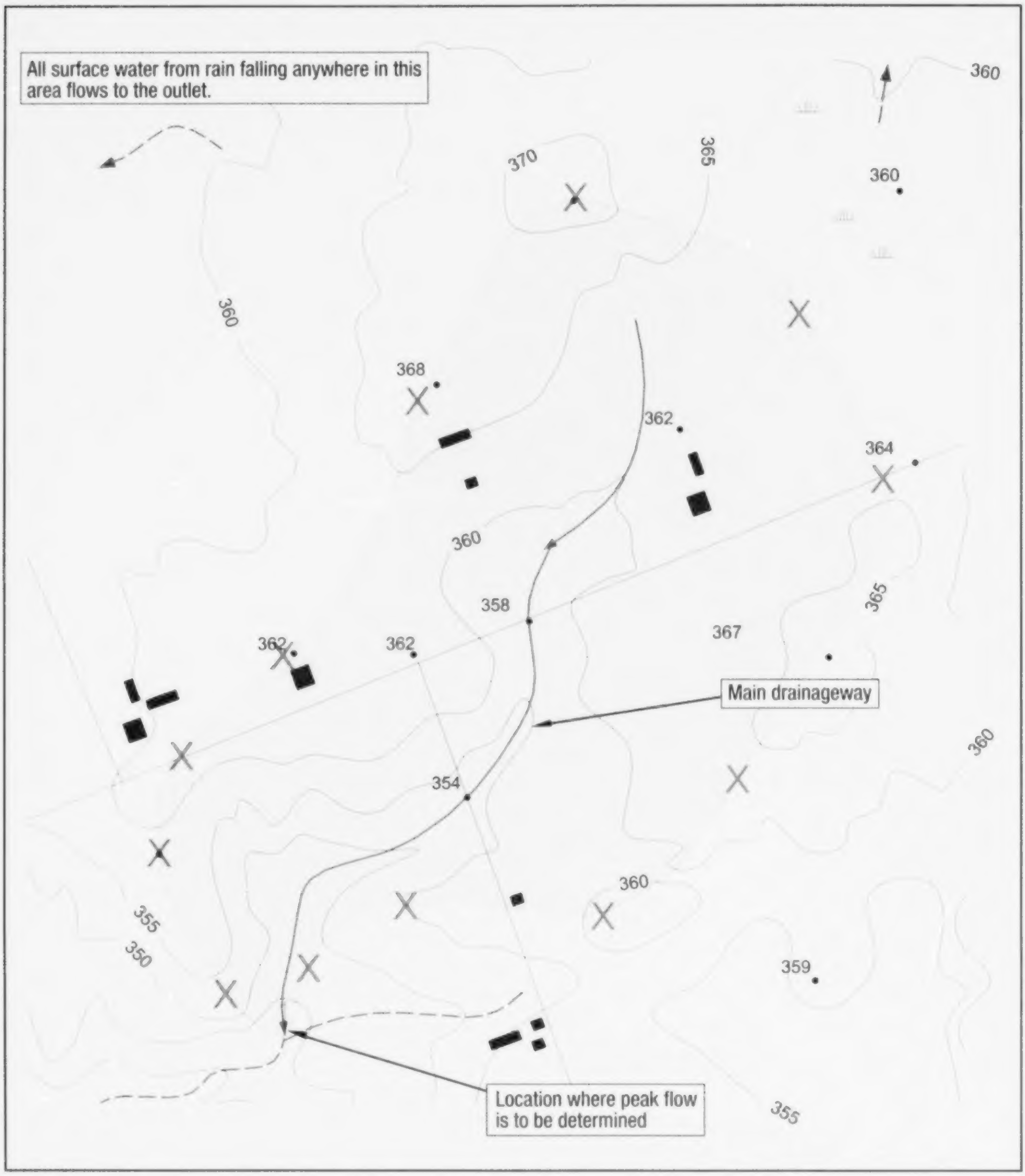


Figure 2.10. Delineating a Watershed Using a Contour Map – Finished Map

2.2.3 Determining the Size of a Watershed

Once the watershed boundary is defined on a scaled plan, map or photo, several methods can be used to obtain the area within the boundary.

Mathematical Calculations – Use mathematical calculations to determine the watershed area, especially if its shape is reasonably close to a rectangle or triangle. If this isn't the case, use the following methods.

Scaled Paper, Areagraph Set, etc. – Lay squares or dots, each representing a known area, over the plan. Count the number of squares or dots within the boundaries and multiply by the known area per square or dot. This will give an estimated area within the boundaries. The accuracy of this method improves with an increase in the number of squares or dots used.

Planimeter – A planimeter is an instrument that automatically calculates the area by moving a marker around the boundary.

Computer Aided – Many Geographic Information System (GIS)-based computer mapping applications offer the ability to measure watershed size on the desktop.

Total Station and GPS Technology – Global Positioning System (GPS) is a worldwide radio navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions, accurate to a matter of metres. Some advanced forms of GPS can make measurements to within a centimetre ($^1/_2$ inch). It's like giving every square metre on the planet a unique address. Many contractors and farmers commonly use GPS as part of their construction equipment and farm machinery. GPS and total survey station technology can work seamlessly to produce contour maps. Other computer software can be integrated to delineate watersheds automatically.

Once the area within the plan, map or photo is determined, multiply by the scale of the plan twice to obtain the actual calculated area of the watershed.

2.2.4 Example

Figure 2.11 shows an example watershed outlined on a topographic map. The scale of the topographic map is 1:25000. As already outlined in this section, there are several ways of calculating the watershed area on the map.

1. The first method is the mathematical approach. A triangle can be estimated with a 64 mm (2.5 in.) wide base and a 44 mm (1.75 in.) height (Figure 2.12). The area of a triangle is calculated by multiplying base times height and dividing by two. The resulting calculations are 64 mm x 44 mm ÷ 2 = 1,408 mm^2 (2.5 in. x 1.75 in. ÷ 2 = 2.19 in.^{2}).
2. The second method is the areagraph method. Graph paper is used to calculate the watershed area. Figure 2.13-M (2.13-I) shows the example map overlain with metric and imperial graph paper.
3. In Figure 2.13-M, approximately 14 squares can be counted within the watershed boundary, which converts to 14 cm^2.
4. In Figure 2.13-I, approximately 220 small divisions can be counted within the boundary. The graph paper has 10 divisions per inch, which converts to 100 divisions per square inch. To find the map area, divide the number of divisions counted by the number of divisions per square inch. There are 2.2 in.^{2} within the boundary.

The mathematical and areagraph methods provide similar results, with the areagraph normally being the most accurate.

From Figure 2.13-M, the map area is about 14 cm^2. To convert the map area to actual area, go to Table 2.1 Scale Conversion Tables – Metric Scale Conversion Table and multiply the calculated map area by the indicated conversion factor. The actual area is 14 cm^2 x 6.25 ha/cm^2 = 87.5 ha (216 ac).

From Figure 2.13-I, the map area is about 2.2 $in.^2$. To convert the map area to actual area, go to Table 2.1 Scale Conversion Tables – Imperial Scale Conversion Table and multiply the calculated map area by the indicated conversion factor. The actual area is 2.2 $in.^2$ x 99.639 acres/$in.^2$ = 219.2 ac.

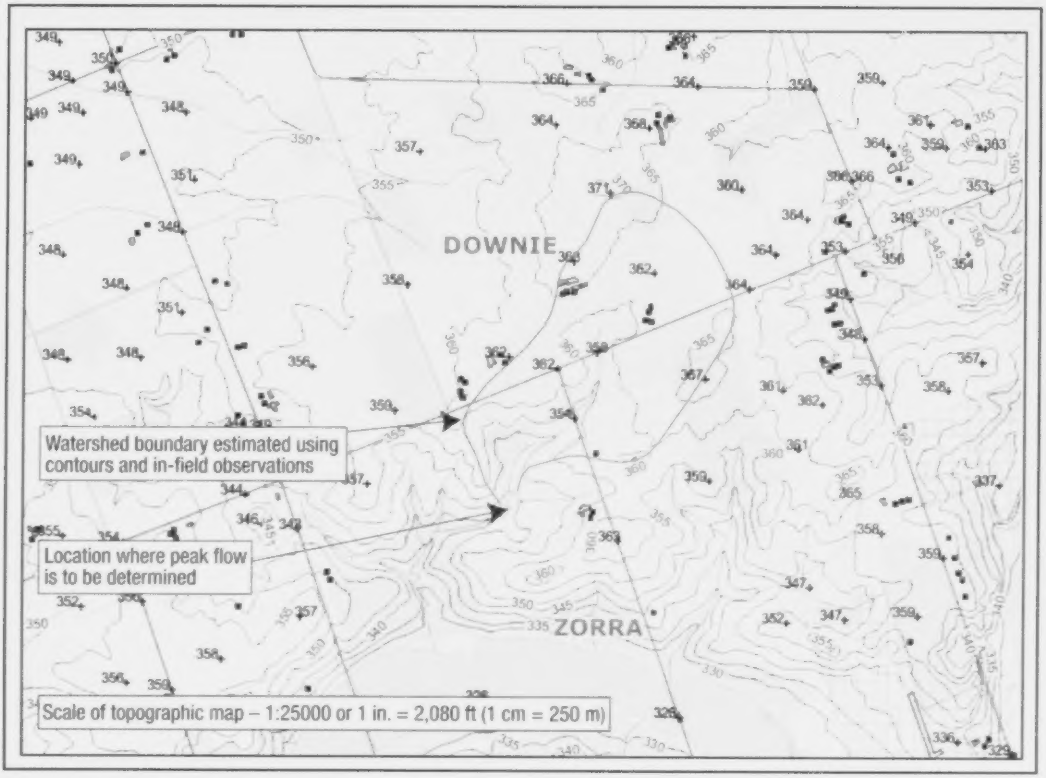


Figure 2.11. Watershed Size Example Map

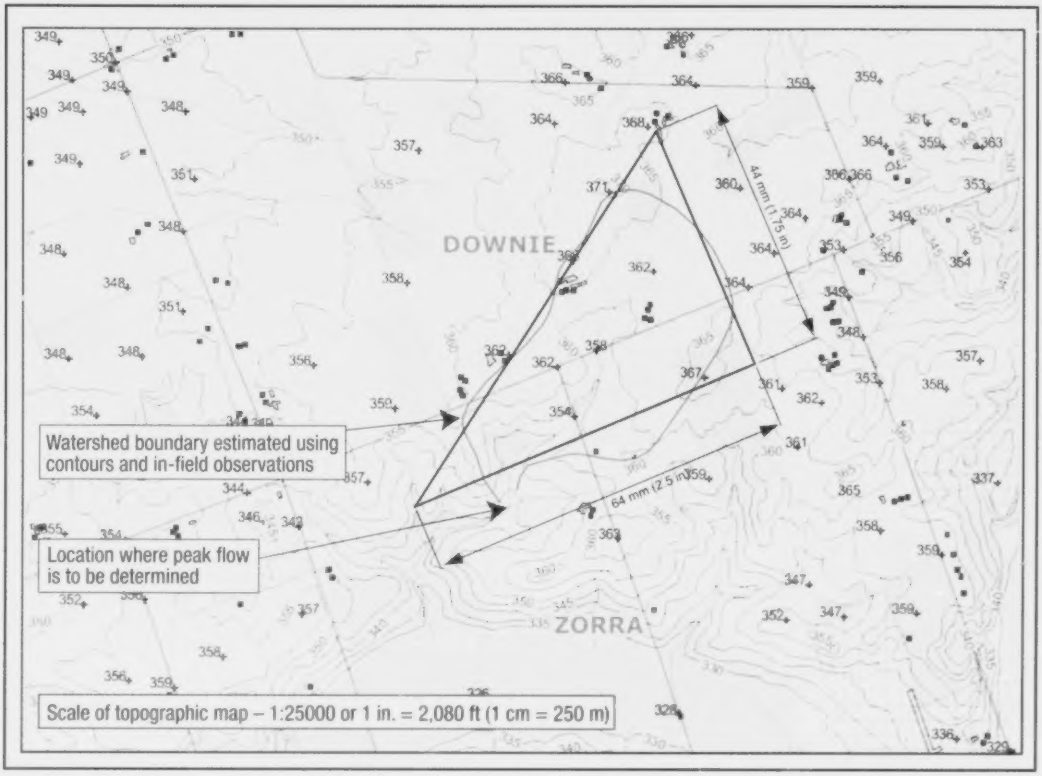


Figure 2.12. Determining the Size of a Watershed Using a Contour Map and Mathematical Equations

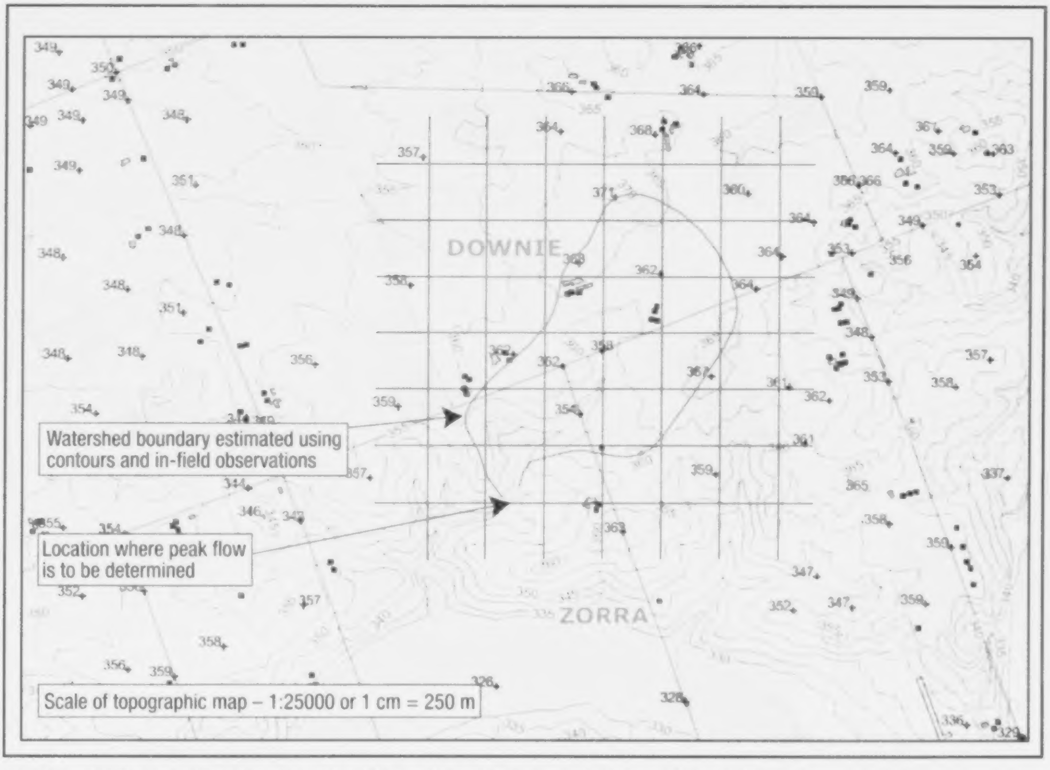


Figure 2.13-M. Determining the Size of a Watershed Using Graph Paper

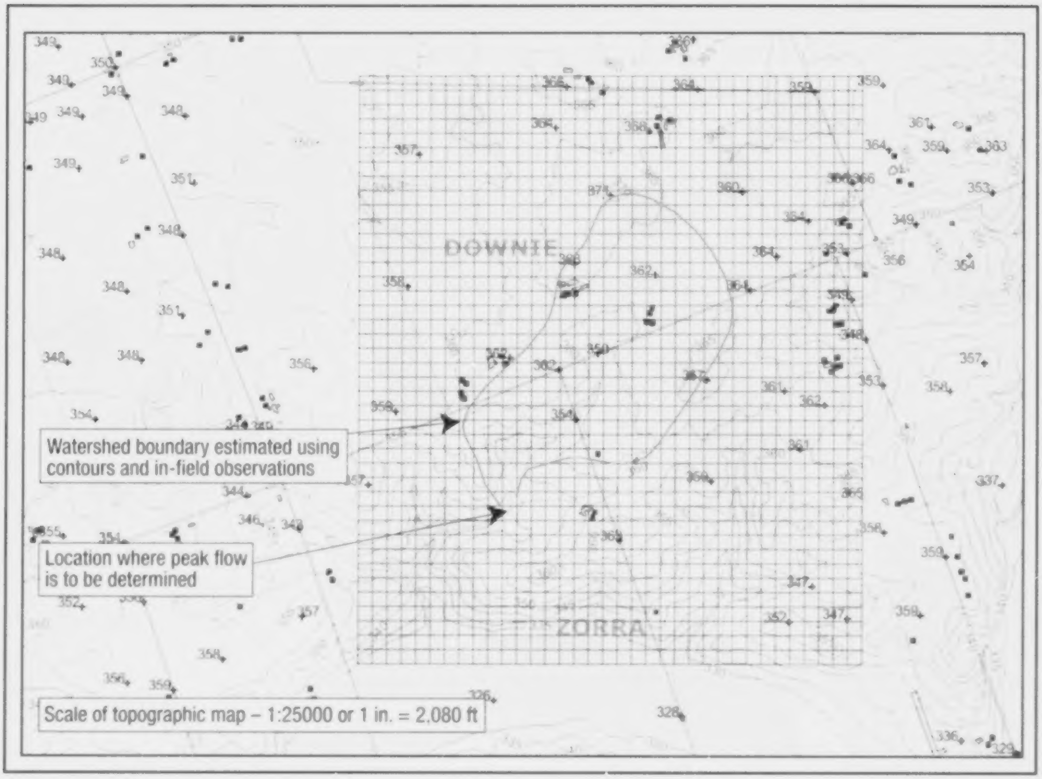


Figure 2.13-I. Determining the Size of a Watershed Using Graph Paper

Table 2.1 provides metric and imperial scale conversion information.

Metric example: On a map with a scale of 1:5000, measuring a length of 10 mm or 1 cm on the map means the actual distance on the ground is 50 m or 0.05 km.

Imperial example: On a map with a scale of 1:10000, measuring a distance 1 inch on the map means the actual distance on the ground is 833.33 ft or 0.158 miles.

Table 2.1. Scale Conversion Tables

Metric Scale Conversion Table

Scale	m/cm	m/mm	km/cm	ha/cm^2
1:1000	10	1	0.01	0.01
1:1200	12	1.2	0.012	0.0144
1:2000	20	2	0.2	0.04
1:2400	24	2.4	0.024	0.0576
1:5000	50	5	0.05	0.25
1:10000	100	10	0.1	1
1:20000	200	20	0.2	4
1:25000	250	25	0.25	6.25
1:50000	500	50	0.5	25
1:63360	633.6	63.36	0.6336	40.14

Imperial Scale Conversion Table

Scale	ft/in.	mi/in.	ac/in.^{2}
1:1000	83.33	0.016	0.159
1:1200	100.00	0.019	0.230
1:2000	166.67	0.032	0.638
1:2400	200.00	0.038	0.918
1:5000	416.67	0.079	3.986
1:10000	833.33	0.158	15.942
1:20000	1,666.67	0.316	63.769
1:25000	2,083.33	0.395	99.639
1:50000	4,166.66	0.789	398.550
1:63360	5,280.00	1.000	640.000

2.3 Flow Determination

When designing structures to solve erosion problems, one of the first questions to ask is, "How much water is involved?" There are many methods for determining the volume of water accumulating on agricultural land following storms of varying intensity. Drainage contractors are familiar with the concept of designing drainage systems for a specific amount of rain, such as 12.5 mm (½ in.) filtering through the soil and reaching a tile in 24 hours. This figure is multiplied by the area of the watershed to estimate the total volume of water reaching the tile in 24 hours, which is then used to determine tile size.

When designing drop pipe inlets, waterways and rock chutes, it's impossible to design for such a uniform flow of water. There are many factors that influence the rate surface water accumulates and flows following a rainfall, including watershed size, slope, length and shape, vegetative cover, soil type and moisture content, and cropping and tillage practices.

Watershed Size – A larger watershed yields more runoff than a smaller one with the same characteristics.

Watershed Slope or Gradient – A steeper watershed allows water to accumulate and flow to the outlet more quickly than a flatter watershed.

Watershed Length and General Shape – A long, narrow watershed has a smaller, delayed peak flow reaching an outlet compared to a short, wide watershed of the same area. Water is forced to travel a longer distance resulting in more water being absorbed by the soil and taking longer for remaining water to arrive at the outlet.

Type of Vegetative Cover – Tall, dense grass traps and holds water long enough for more to be absorbed into the soil. Corn, beans and other row crops don't hold water back as well. As a result, surface water accumulates and reaches an outlet much more quickly in a watershed with row crops than in a watershed with heavy grasses.

Soil Type – Heavy clay doesn't absorb water as quickly as a deep sand soil formation. So in a predominantly clay watershed, more water flows across the surface. Water flow also reaches an outlet more quickly and in larger quantities than in a sandy watershed.

Soil Moisture Content – Dry soil conditions enable more rain water to be absorbed, reducing the amount of surface water reaching the outlet. A heavy rainfall on saturated soil results in more runoff and erosion damage.

Cropping and Tillage Practices – Cropping practices affect the rate water runs off agricultural land. Good crop rotations and choice of crop improve the tilth of the soil, increasing its ability to absorb water. Cropping across slopes, strip-cropping and contour cropping all help reduce the amount of runoff reaching an outlet by providing small storage pockets where water can accumulate and soak into the ground. Tillage practices have a similar impact on runoff. Methods of tillage that maintain as much residue as possible on the soil surface – such as mulch-till or no-till – reduce the amount of runoff. The more residue left on the soil's surface, the less runoff occurs.

Calculating the quantity of surface water flowing from agricultural lands, or flow rates, requires an understanding of the term "storm return period." Return period is the length of time within which it's probable that a storm of a particular intensity will occur. For example, extremely severe storms are expected less frequently than minor storms, making the return period of a severe storm longer than that of a minor storm.

There is no hard and fast rule for the return period used when designing soil erosion structures. In general, use a longer return period where there is large financial investment in a structure or where serious consequences could result in the event of a structural failure. This will increase the size and cost of the installation, but provides a larger safety margin.

The largest return period in most agricultural situations is 25 years. In-field water storage structures and gully erosion projects are usually designed for a minimum 10-year return storm. They also require an emergency overflow structure capable of handling flow rates experienced in a 25-year storm. The structure size can be reduced where a pond or temporary storage is used to buffer the incoming quantities of water. Section 4 describes the effects of ponding water on the peak flow of water exiting a watershed.

Many other structures can't feasibly be designed for these quantities of water. A tile/catch basin surface water inlet may be designed for a two-year storm or less. Designing for more can be very costly. Grassed waterways don't need to be designed for a return period exceeding their useful life, commonly suggested as a 10-year flow rate. Suggestions for appropriate return periods for specific types of structures are in later sections.

Many methods have been suggested over the years for calculating flow rates of surface water exiting from an agricultural watershed. The following U.S. Soil Conservation Service (SCS) method accounts for all factors listed above.

Work Sheet to Determine Peak Flow Rate from an Agricultural Watershed

Watershed characteristics

1. Watershed size		_____ ha	_____ ac
2. Watershed length		_____ m	_____ ft
3. Elevation difference over length of watershed		_____ m	_____ ft
4. Average grade of watershed $\frac{\text{Elevation difference}}{\text{Watershed length}} \times 100 =$	$\frac{\_\_\_\_\_ \text{ m}}{\text{m}} \times 100$	$\frac{\_\_\_\_\_ \text{ ft}}{\text{ft}} \times 100$	_____ %
5. Hydrologic soil group from Table 2.2 or OMAFRA Publication 29, *Drainage Guide for Ontario*			_____
6. Hydrologic condition from Table 2.3			_____
7. Runoff curve number from Table 2.4			_____

8. Choose the appropriate peak flow chart based on runoff curve number, i.e. Table 2.5-M to 2.11-M (2.5-I to 2.11-I). Read watershed area across the top of the figure and average grade along the left side. Enter the peak flow rates for the appropriate return periods into the chart below.

Storm Return Period	Flow Rate (m^3/s)	Flow Rate (ft^3/s)
2 years		
5 years		
10 years		
25 years		

Use the appropriate peak flows to design various structures as outlined in Section 4.

Work Sheet to Determine Peak Flow Rate from an Agricultural Watershed – Example Problem #1

Watershed characteristics

1. Watershed size		40 ha	100 ac
2. Watershed length		1,300 m	4,300 ft
3. Elevation difference over length of watershed		6.40 m	21 ft
4. Average grade of watershed			
$\frac{\text{Elevation difference}}{\text{Watershed length}} \times 100 =$	$\frac{6.4\text{ m}}{1{,}300\text{ m}} \times 100$	$\frac{21\text{ ft}}{4{,}300\text{ ft}} \times 100$	0.49%
5. Hydrologic soil group from Table 2.2 or OMAFRA Publication 29, *Drainage Guide for Ontario*			B
6. Hydrologic condition from Table 2.3			good
7. Runoff curve number from Table 2.4			75

8. Choose the appropriate peak flow chart based on runoff curve number, i.e. Table 2.5-M to 2.11-M (2.5-I to 2.11-I). Read watershed area across the top of the figure and average grade along the left side. Enter the peak flow rates for the ap¬propriate return periods into the chart below.

Storm Return Period	Flow Rate (m^3/s)	Flow Rate (ft^3/s)
2 years	0.147	5.2
5 years	0.365	12.9
10 years	0.629	22.2
25 years	0.960	33.9

Work Sheet to Determine Peak Flow Rate from an Agricultural Watershed – Example Problem #2

See watershed sizing example in Section 2.2.4 for watershed area. See Figure 2.14 Determining the Average Grade and Length of a Watershed.

Watershed characteristics

<table>
<tr><td colspan="3">1. Watershed size</td><td>87.5 ha</td><td>216 ac</td></tr>
<tr><td colspan="3">2. Watershed length</td><td>1,787 m</td><td>5,863 ft</td></tr>
<tr><td colspan="3">3. Elevation difference over length of watershed</td><td>28.15 m</td><td>92.5 ft</td></tr>
<tr><td colspan="3">4. Average grade of watershed</td><td colspan="2" rowspan="2">1.58%</td></tr>
<tr><td>$\frac{\text{Elevation difference}}{\text{Watershed length}} \times 100 =$</td><td>$\frac{28.15\text{ m}}{1{,}787\text{ m}} \times 100$</td><td>$\frac{92.5\text{ ft}}{5{,}863\text{ ft}} \times 100$</td></tr>
<tr><td colspan="3">5. Hydrologic soil group from Table 2.2 or OMAFRA Publication 29, Drainage Guide for Ontario</td><td colspan="2">B</td></tr>
<tr><td colspan="3">6. Hydrologic condition from Table 2.3</td><td colspan="2">good</td></tr>
<tr><td colspan="3">7. Runoff curve number from Table 2.4</td><td colspan="2">75</td></tr>
</table>

8. Choose the appropriate peak flow chart based on runoff curve number from Table 2.7-M (Table 2.7-I). Read watershed area across the top of the figure and average grade along the left side. Enter the peak flow rates for the appropriate return periods into the chart below.

Storm Return Period	Flow Rate (m^3/s)	Flow Rate (ft^3/s)
2 years	0.32	11.3
5 years	0.82	29
10 years	1.4	49
25 years	2.2	76

Use the appropriate peak flows to design various structures as outlined in Section 4.

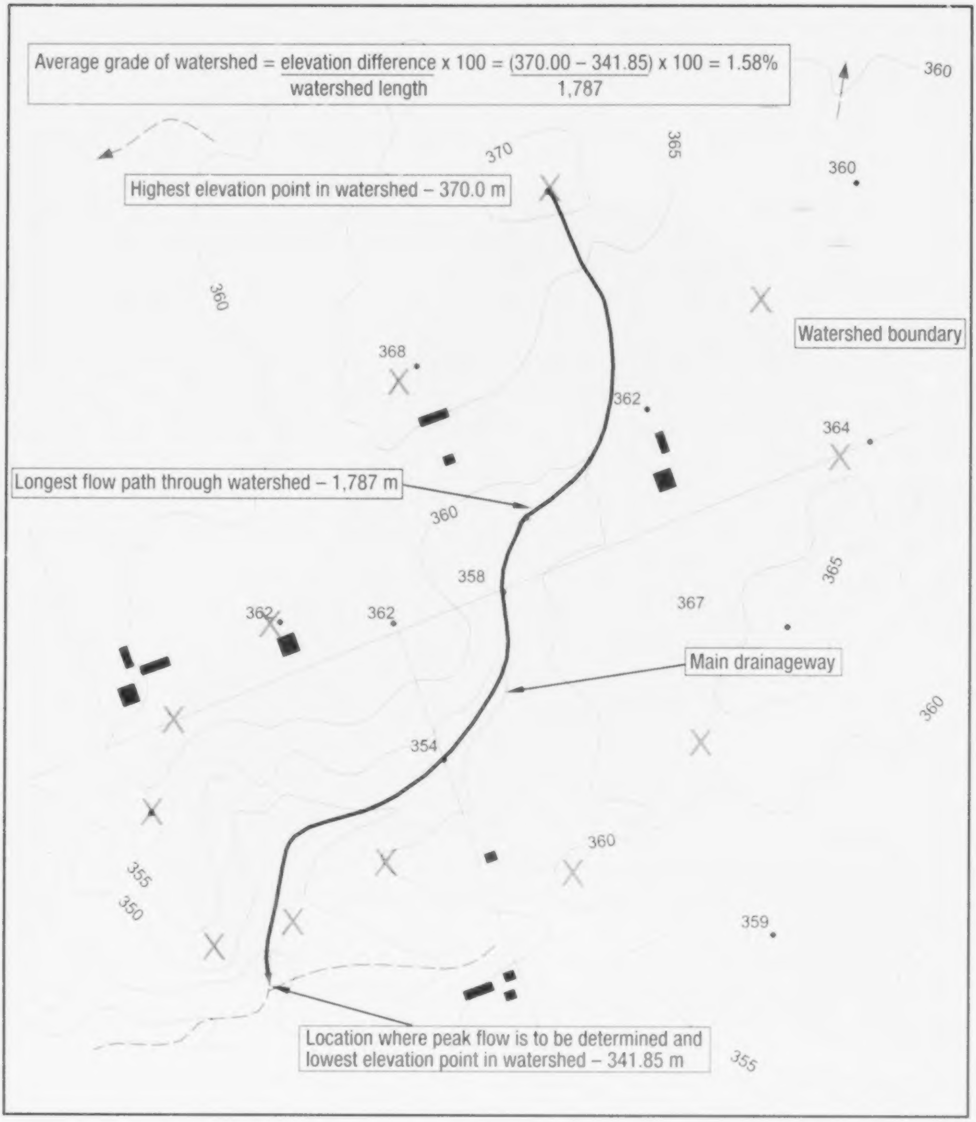


Figure 2.14. Determining the Average Grade and Length of a Watershed

This example problem is used in the design of a grassed waterway in the Grassed Waterway Example Problem #2 in Section 4.

Table 2.2. Determination of Hydrologic Soil Group (SCS Method)

Soil Group	Description
Group A (lowest runoff potential)	Includes deep sands with very little silt and clay, as well as deep rapidly permeable loess
Group B	Comprises mostly sandy soils shallower than Group A, and less deep or less aggregated than Group A; the group as a whole has above average infiltration following a thorough wetting
Group C	Comprises shallower soils and soils containing considerable clay and colloid, though less than those of Group D; the group has below average infiltration after pre-saturation
Group D (highest runoff potential)	Includes mostly clays of high swelling percent; the group also includes some shallow soils with nearly impermeable sub-horizons near the surface

Table 2.3. Determination of Watershed Hydrologic Condition

Hydrologic Conditions	Pasture or Range	Woodland
Poor	Heavily grazed, no mulch or has plant cover on 50% of the area	Heavily grazed or regularly burned so that litter, small trees and brush are destroyed
Fair	Moderately grazed, about 50% to 75% of the area has plant cover	Grazed but not burned; there may be some litter but these woodlands are not fully protected from grazing
Good	Lightly grazed, more than about 75% of the area has plant cover	Protected from grazing so that litter and shrubs cover the soil

Crop rotations range from poor to good in proportion to the amount of dense vegetation in the rotation. Poor rotations (from a hydrologic standpoint) contain row crops, small grains and fallow in various combinations. Good rotations contain a high proportion of alfalfa or other close-seeded legumes or grasses that improve the tilth and increase infiltration.

Table 2.4. Determination of Runoff Curve Number

Land Use or Cover	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Fallow	Straight row	—	77	86	91	94
Row Crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	78	81
Small Grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close Seeded Legumes (close-drilled or broadcast) or Rotation Meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
		Good	51	67	76	80
Pasture or Range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
		Fair	25	59	75	83
		Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods and Forest		Very Poor	56	75	86	91
		Fair	36	60	73	79
		Very Good	15	44	54	61
Farmsteads			59	74	82	86
Roads (include right-of-way) – dirt			72	82	87	89
Roads (include right-of-way) – hard			74	84	90	92

Table 2.5-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 65

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.003	0.006	0.014	0.028	0.057	0.085	0.113	0.170
	0.008	0.014	0.037	0.076	0.147	0.221	0.294	0.433
	0.014	0.031	0.076	0.147	0.292	0.433	0.575	0.847
	0.025	0.051	0.125	0.246	0.484	0.716	0.954	1.390
0.5	0.003	0.006	0.014	0.028	0.057	0.085	0.113	0.170
	0.008	0.014	0.040	0.076	0.150	0.224	0.297	0.442
	0.014	0.031	0.076	0.150	0.297	0.442	0.586	0.864
	0.025	0.051	0.127	0.252	0.495	0.733	0.977	1.430
1.0	0.003	0.006	0.014	0.028	0.057	0.085	0.116	0.173
	0.008	0.014	0.040	0.076	0.153	0.227	0.303	0.447
	0.014	0.031	0.076	0.153	0.300	0.447	0.597	0.881
	0.025	0.051	0.130	0.255	0.504	0.747	0.997	1.467
2.0	0.003	0.006	0.014	0.028	0.057	0.088	0.116	0.173
	0.008	0.014	0.040	0.076	0.153	0.229	0.306	0.453
	0.017	0.031	0.076	0.153	0.303	0.453	0.603	0.895
	0.025	0.054	0.130	0.258	0.510	0.759	1.014	1.495
4.0	0.003	0.006	0.014	0.028	0.057	0.088	0.116	0.173
	0.008	0.017	0.040	0.076	0.153	0.229	0.306	0.456
	0.017	0.031	0.076	0.156	0.306	0.459	0.609	0.906
	0.025	0.054	0.130	0.260	0.515	0.770	1.025	1.520
8.0	0.003	0.006	0.014	0.028	0.057	0.088	0.116	0.173
	0.008	0.017	0.040	0.076	0.156	0.232	0.309	0.461
	0.017	0.031	0.079	0.156	0.309	0.461	0.614	0.914
	0.025	0.054	0.133	0.263	0.521	0.779	1.036	1.540

Table 2.5-I. Peak Flows (Q) from a Watershed (ft^3/s), Runoff Curve Number 65

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	0.1	0.2	0.5	1.0	2.0	3.0	4.0	6.0
	0.3	0.5	1.3	2.7	5.2	7.8	10.4	15.3
	0.5	1.1	2.7	5.2	10.3	15.3	20.3	29.9
	0.9	1.8	4.4	8.7	17.1	25.3	33.7	49.1
0.5	0.1	0.2	0.5	1.0	2.0	3.0	4.0	6.0
	0.3	0.5	1.4	2.7	5.3	7.9	10.5	15.6
	0.5	1.1	2.7	5.3	10.5	15.6	20.7	30.5
	0.9	1.8	4.5	8.9	17.5	25.9	34.5	50.5
1.0	0.1	0.2	0.5	1.0	2.0	3.0	4.1	6.1
	0.3	0.5	1.4	2.7	5.4	8.0	10.7	15.8
	0.5	1.1	2.7	5.4	10.6	15.8	21.1	31.1
	0.9	1.8	4.6	9.0	17.8	26.4	35.2	51.8
2.0	0.1	0.2	0.5	1.0	2.0	3.1	4.1	6.1
	0.3	0.5	1.4	2.7	5.4	8.1	10.8	16.0
	0.6	1.1	2.7	5.4	10.7	16.0	21.3	31.6
	0.9	1.9	4.6	9.1	18.0	26.8	35.8	52.8
4.0	0.1	0.2	0.5	1.0	2.0	3.1	4.1	6.1
	0.3	0.6	1.4	2.7	5.4	8.1	10.8	16.1
	0.6	1.1	2.7	5.5	10.8	16.2	21.5	32.0
	0.9	1.9	4.6	9.2	18.2	27.2	36.2	53.7
8.0	0.1	0.2	0.5	1.0	2.0	3.1	4.1	6.1
	0.3	0.6	1.4	2.7	5.5	8.2	10.9	16.3
	0.6	1.1	2.8	5.5	10.9	16.3	21.7	32.3
	0.9	1.9	4.7	9.3	18.4	27.5	36.6	54.4

Table 2.6-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 70

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.006	0.008	0.023	0.045	0.091	0.113	0.176	0.263
	0.011	0.025	0.059	0.116	0.229	0.337	0.444	0.654
	0.023	0.045	0.110	0.215	0.419	0.617	0.813	1.192
	0.037	0.074	0.176	0.343	0.668	0.980	1.286	1.880
0.5	0.006	0.008	0.023	0.045	0.091	0.113	0.178	0.263
	0.011	0.025	0.059	0.119	0.232	0.345	0.456	0.674
	0.023	0.045	0.110	0.221	0.430	0.634	0.838	1.235
	0.037	0.074	0.181	0.354	0.688	1.014	1.334	1.960
1.0	0.006	0.008	0.023	0.045	0.091	0.136	0.181	0.269
	0.011	0.025	0.059	0.119	0.238	0.351	0.464	0.691
	0.023	0.045	0.113	0.224	0.439	0.651	0.858	1.268
	0.037	0.076	0.184	0.362	0.708	1.042	1.376	2.027
2.0	0.006	0.008	0.023	0.045	0.091	0.136	0.181	0.272
	0.011	0.025	0.062	0.122	0.231	0.357	0.473	0.702
	0.023	0.045	0.116	0.226	0.447	0.665	0.878	1.302
	0.037	0.076	0.187	0.368	0.722	1.070	1.413	2.084
4.0	0.006	0.008	0.023	0.045	0.091	0.136	0.184	0.272
	0.011	0.025	0.062	0.122	0.244	0.362	0.481	0.716
	0.023	0.048	0.116	0.229	0.453	0.674	0.895	1.328
	0.040	0.076	0.190	0.374	0.736	1.093	1.447	2.141
8.0	0.006	0.008	0.023	0.045	0.093	0.139	0.184	0.275
	0.011	0.025	0.062	0.124	0.246	0.365	0.487	0.725
	0.023	0.048	0.116	0.232	0.459	0.685	0.906	1.351
	0.040	0.076	0.190	0.377	0.748	1.113	1.475	2.189

Table 2.6-I. Peak Flows (Q) from a Watershed (ft^3/s), Runoff Curve Number 70

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	0.2	0.3	0.8	1.6	3.2	4.7	6.2	9.3
	0.4	0.9	2.1	4.1	8.1	11.9	15.7	23.1
	0.8	1.6	3.9	7.6	14.8	21.8	28.7	42.1
	1.3	2.6	6.2	12.1	23.6	34.6	45.4	66.4
0.5	0.2	0.3	0.8	1.6	3.2	4.7	6.3	9.3
	0.4	0.9	2.1	4.2	8.2	12.2	16.1	23.8
	0.8	1.6	3.9	7.8	15.2	22.4	29.6	43.6
	1.3	2.6	6.4	12.5	24.3	35.8	47.1	69.2
1.0	0.2	0.3	0.8	1.6	3.2	4.8	6.4	9.5
	0.4	0.9	2.1	4.2	8.4	12.4	16.4	24.4
	0.8	1.6	4.0	7.9	15.5	23.0	30.3	44.8
	1.3	2.7	6.5	12.8	25.0	36.8	48.5	71.6
2.0	0.2	0.3	0.8	1.6	3.2	4.8	6.4	9.6
	0.4	0.9	2.2	4.3	8.5	12.6	16.7	24.8
	0.8	1.6	4.1	8.0	15.8	23.5	31.0	46.0
	1.3	2.7	6.6	13.0	25.5	37.8	49.9	73.6
4.0	0.2	0.3	0.8	1.6	3.2	4.8	6.5	9.6
	0.4	0.9	2.2	4.3	8.6	12.8	17.0	25.3
	0.8	1.7	4.1	8.1	16.0	23.8	31.6	46.9
	1.4	2.7	6.7	13.2	26.0	38.6	51.1	75.6
8.0	0.2	0.3	0.8	1.6	3.3	4.9	6.5	9.7
	0.4	0.9	2.2	4.4	8.7	12.9	17.2	25.6
	0.8	1.7	4.1	8.2	16.2	24.2	32.0	47.7
	1.4	2.7	6.7	13.3	26.4	39.3	52.1	77.3

Table 2.7-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 75

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.008	0.014	0.037	0.074	0.144	0.212	0.280	0.416
	0.020	0.040	0.093	0.184	0.351	0.518	0.680	0.991
	0.034	0.068	0.161	0.314	0.603	0.883	1.152	1.682
	0.054	0.105	0.249	0.478	0.917	0.342	1.753	2.543
0.5	0.008	0.014	0.037	0.074	0.147	0.218	0.286	0.425
	0.020	0.040	0.096	0.190	0.365	0.538	0.705	1.036
	0.034	0.068	0.167	0.323	0.629	0.923	1.209	1.764
	0.054	0.108	0.258	0.501	0.960	1.402	1.838	2.681
1.0	0.008	0.014	0.037	0.074	0.147	0.221	0.292	0.433
	0.020	0.040	0.099	0.192	0.377	0.555	0.730	1.073
	0.037	0.071	0.173	0.334	0.646	0.954	1.254	1.843
	0.057	0.110	0.266	0.518	1.002	1.467	1.920	2.800
2.0	0.008	0.014	0.037	0.076	0.150	0.224	0.297	0.442
	0.020	0.040	0.099	0.195	0.385	0.572	0.753	1.110
	0.037	0.071	0.176	0.343	0.668	0.982	1.294	1.908
	0.057	0.110	0.272	0.532	1.036	1.526	2.002	2.934
4.0	0.008	0.014	0.040	0.076	0.150	0.226	0.300	0.447
	0.020	0.042	0.099	0.198	0.394	0.583	0.770	1.141
	0.037	0.074	0.178	0.351	0.685	1.014	1.336	1.965
	0.057	0.113	0.278	0.544	1.065	1.574	2.073	3.050
8.0	0.008	0.014	0.040	0.076	0.153	0.226	0.303	0.450
	0.020	0.042	0.099	0.204	0.399	0.592	0.787	1.167
	0.037	0.074	0.181	0.357	0.699	1.039	1.373	2.027
	0.057	0.113	0.280	0.522	1.087	1.611	2.129	3.146

Table 2.7-I. Peak Flows (Q) from a Watershed (ft^3/s), Runoff Curve Number 75

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	0.3	0.5	1.3	2.6	5.1	7.5	9.9	14.7
	0.7	1.4	3.3	6.5	12.4	18.3	24.0	35.0
	1.2	2.4	5.7	11.1	21.3	31.2	40.7	59.4
	1.9	3.7	8.8	16.9	32.4	47.4	61.9	89.8
0.5	0.3	0.5	1.3	2.6	5.2	7.7	10.1	15.0
	0.7	1.4	3.4	6.7	12.9	19.0	24.9	36.6
	1.2	2.4	5.9	11.4	22.2	32.6	42.7	62.3
	1.9	3.8	9.1	17.7	33.9	49.5	64.9	94.7
1.0	0.3	0.5	1.3	2.6	5.2	7.8	10.3	15.3
	0.7	1.4	3.5	6.8	13.3	19.6	25.8	37.9
	1.3	2.5	6.1	11.8	22.8	33.7	44.3	65.1
	2.0	3.9	9.4	18.3	35.4	51.8	67.8	98.9
2.0	0.3	0.5	1.3	2.7	5.3	7.9	10.5	15.6
	0.7	1.4	3.5	6.9	13.6	20.2	26.6	39.2
	1.3	2.5	6.2	12.1	23.6	34.7	45.7	67.4
	2.0	3.9	9.6	18.8	36.6	53.9	70.7	103.6
4.0	0.3	0.5	1.4	2.7	5.3	8.0	10.6	15.8
	0.7	1.5	3.6	7.0	13.9	20.6	27.2	40.3
	1.3	2.6	6.3	12.4	24.2	35.8	47.2	69.4
	2.0	4.0	9.8	19.2	37;6	55.6	73.2	107.7
8.0	0.3	0.5	1.4	2.7	5.4	8.0	10.7	15.9
	0.7	1.5	3.6	7.2	14.1	20.9	27.8	41.2
	1.3	2.6	6.4	12.6	24.7	36.7	48.5	71.6
	2.0	4.0	9.9	19.5	38.4	56.9	75.2	111.1

Table 2.8-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 80

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.014	0.025	0.062	0.122	0.238	0.348	0.459	0.671
	0.034	0.062	0.153	0.292	0.552	0.798	1.033	1.501
	0.054	0.102	0.241	0.462	0.878	1.268	1.642	2.367
	0.079	0.153	0.354	0.671	1.274	1.840	2.387	3.424
0.5	0.014	0.025	0.065	0.125	0.244	0.362	0.476	0.699
	0.034	0.065	0.156	0.303	0.580	0.847	1.104	1.594
	0.057	0.108	0.252	0.481	0.926	1.348	1.753	2.567
	0.082	0.158	0.374	0.705	1.342	1.957	2.546	3.684
1.0	0.014	0.025	0.065	0.127	0.252	0.371	0.490	0.722
	0.034	0.068	0.161	0.314	0.606	0.889	1.164	1.693
	0.057	0.110	0.263	0.504	0.966	1.413	1.849	2.693
	0.085	0.164	0.394	0.750	1.410	2.053	2.687	3.910
2.0	0.014	0.028	0.068	0.130	0.258	0.382	0.504	0.742
	0.037	0.071	0.170	0.326	0.629	0.923	1.215	1.778
	0.059	0.113	0.275	0.527	1.005	1.470	1.931	2.829
	0.088	0.170	0.408	0.787	1.498	2.175	2.823	4.106
4.0	0.014	0.028	0.068	0.133	0.263	0.391	0.515	0.762
	0.037	0.071	0.176	0.337	0.651	0.954	1.257	1.849
	0.059	0.116	0.283	0.549	1.056	1.540	2.010	2.939
	0.088	0.173	0.422	0.818	1.574	2.296	2.999	4.347
8.0	0.014	0.028	0.068	0.136	0.266	0.396	0.524	0.779
	0.037	0.734	0.178	0.348	0.677	0.991	1.300	1.906
	0.059	0.119	0.289	0.566	1.099	1.611	2.112	3.084
	0.091	0.178	0.433	0.844	1.637	2.401	3.149	4.596

Table 2.8-I. Peak Flows (Q) from a Watershed (ft^3/s), Runoff Curve Number 80

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	0.5	0.9	2.2	4.3	8.4	12.3	16.2	23.7
	1.2	2.2	5.4	10.3	19.5	28.2	36.5	53.0
	1.9	3.6	8.5	16.3	31.0	44.8	58.0	83.6
	2.8	5.4	12.5	23.7	45.0	65.0	84.3	120.9
0.5	0.5	0.9	2.3	4.4	8.6	12.8	16.8	24.7
	1.2	2.3	5.5	10.7	20.5	29.9	39.0	56.3
	2.0	3.8	8.9	17.0	32.7	47.6	61.9	89.6
	2.9	5.6	13.2	24.9	47.4	69.1	89.9	130.1
1.0	0.5	0.9	2.3	4.5	8.9	13.1	17.3	25.5
	1.2	2.4	5.7	11.1	21.4	31.4	41.1	59.8
	2.0	3.9	9.3	17.8	34.1	49.9	65.3	95.1
	3.0	5.8	13.9	26.5	49.8	72.5	94.9	138.1
2.0	0.5	1.0	2.4	4.6	9.1	13.5	17.8	26.2
	1.3	2.5	6.0	11.5	22.2	32.6	42.9	62.8
	2.1	4.0	9.7	18.6	35.5	51.9	68.2	99.9
	3.1	6.0	14.4	27.8	52.9	76.8	99.7	145.0
4.0	0.5	1.0	2.4	4.7	9.3	13.8	18.2	26.9
	1.3	2.5	6.2	11.9	23.0	33.7	44.4	65.3
	2.1	4.1	10.0	19.4	37.3	54.4	71.0	103.8
	3.1	6.1	14.9	28.9	55.6	81.1	105.9	153.5
8.0	0.5	1.0	2.4	4.8	9.4	14.0	18.5	27.5
	1.3	2.6	6.3	12.3	23.9	35.0	45.9	67.3
	2.1	4.2	10.2	20.0	38.8	56.9	74.6	108.9
	3.2	6.3	15.3	29.8	57.8	84.8	111.2	162.3

Table 2.9-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 85

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.025	0.048	0.113	0.215	0.408	0.589	0.762	1.107
	0.057	0.108	0.252	0.467	0.858	1.229	1.591	2.282
	0.085	0.161	0.371	0.691	1.266	1.809	2.345	3.364
	0.116	0.224	0.518	0.963	1.761	2.492	3.228	4.630
0.5	0.025	0.048	0.116	0.224	0.428	0.626	0.813	1.175
	0.059	0.113	0.266	0.504	0.937	1.336	1.713	2.458
	0.088	0.167	0.396	0.745	1.382	1.974	2.532	3.622
	0.122	0.235	0.549	1.036	1.926	2.747	3.525	4.981
1.0	0.025	0.051	0.119	0.232	0.447	0.657	0.858	1.249
	0.059	0.119	0.280	0.535	1.008	1.450	1.872	2.670
	0.090	0.176	0.416	0.790	1.489	2.144	2.766	3.947
	0.124	0.244	0.578	1.102	2.073	2.982	3.851	5.496
2.0	0.025	0.051	0.124	0.241	0.464	0.682	0.895	1.311
	0.062	0.122	0.292	0.561	1.070	1.552	2.106	2.900
	0.090	0.178	0.430	0.830	1.580	2.294	2.976	4.284
	0.127	0.249	0.600	1.155	2.200	3.191	4.146	5.966
4.0	0.028	0.054	0.127	0.249	0.478	0.702	0.926	1.362
	0.062	0.124	0.300	0.583	1.124	1.640	2.141	3.104
	0.093	0.184	0.444	0.864	1.659	2.424	3.163	4.587
	0.130	0.255	0.620	1.201	2.310	3.372	4.403	6.385
8.0	0.028	0.054	0.113	0.258	0.498	0.730	0.960	1.407
	0.065	0.127	0.309	0.603	1.169	1.716	2.248	3.279
	0.093	0.187	0.446	0.889	0.727	2.534	3.322	4.848
	0.113	0.260	0.634	1.240	2.404	3.528	4.621	6.748

Table 2.9-I. Peak Flows (Q) from a Watershed (ft^3/s), Runoff Curve Number 85

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	0.9	1.7	4.0	7.6	14.4	20.8	26.9	39.1
	2.0	3.8	8.9	16.5	30.3	43.4	56.2	80.6
	3.0	5.7	13.1	24.4	44.7	83.9	82.8	118.8
	4.1	7.9	18.3	34.0	62.2	88.0	114.0	163.5
0.5	0.9	1.7	4.1	7.9	15.1	22.1	28.7	41.5
	2.1	4.0	9.4	17.8	33.1	47.2	60.5	86.8
	3.1	5.9	14.0	26.3	48.8	69.7	89.4	127.9
	4.3	8.3	19.4	36.6	68.0	97.0	124.5	175.9
1.0	0.9	1.8	4.2	8.2	15.8	23.2	30.3	44.1
	2.1	4.2	9.9	18.9	35.6	51.2	66.1	94.3
	3.2	6.2	14.7	27.9	52.6	75.7	97.7	139.4
	4.4	8.6	20.4	38.9	73.2	105.3	136.0	194.1
2.0	0.9	1.8	4.4	8.5	16.4	24.1	31.6	46.3
	2.2	4.3	10.3	19.8	37.8	54.8	71.2	102.4
	3.2	6.3	15.2	29.3	55.8	81.0	105.1	151.3
	4.5	8.8	21.2	40.8	77.7	112.7	146.4	210.7
4.0	1.0	1.9	4.5	8.8	16.9	24.8	32.7	48.1
	2.2	4.4	10.6	20.6	39.7	57.9	75.6	109.6
	3.3	6.5	15.7	30.5	58.6	85.6	111.7	162.0
	4.6	9.0	21.9	42.4	81.6	119.1	155.5	225.5
8.0	1.0	1.9	4.7	9.1	17.6	25.8	33.9	49.7
	2.3	4.5	10.9	21.3	41.3	60.6	79.4	115.8
	3.3	6.6	16.1	31.4	61.0	89.5	117.3	171.2
	4.7	9.2	22.4	43.8	84.9	124.6	163.2	238.3

Table 2.10-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 90

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.051	0.093	0.212	0.394	0.722	1.031	1.367	1.880
	0.105	0.193	0.425	0.773	1.393	1.962	2.605	3.516
	0.142	0.263	0.580	1.056	1.908	2.693	3.576	4.836
	0.190	0.345	0.767	1.390	2.511	3.542	4.703	6.353
0.5	0.054	0.099	0.229	0.425	0.784	1.124	1.492	2.061
	0.113	0.210	0.467	0.852	1.543	2.183	2.896	3.927
	0.156	0.286	0.637	1.164	2.109	2.987	3.964	5.385
	0.204	0.379	0.841	1.535	2.783	3.933	5.221	7.084
1.0	0.057	0.105	0.243	0.464	0.849	1.217	1.617	2.245
	0.122	0.227	0.512	0.957	1.704	2.412	3.205	4.363
	0.167	0.309	0.694	1.305	2.324	3.298	4.380	5.974
	0.221	0.411	0.920	1.724	3.069	4.346	5.773	7.865
2.0	0.059	0.110	0.258	0.487	0.912	1.311	1.744	2.432
	0.130	0.246	0.555	1.022	1.871	2.656	3.528	4.824
	0.178	0.334	0.753	1.390	2.548	3.624	4.813	6.597
	0.238	0.442	0.997	1.840	3.369	4.782	6.353	8.695
4.0	0.059	0.116	0.275	0.518	0.974	1.407	1.871	2.625
	0.142	0.263	0.600	1.107	2.044	2.911	3.867	5.311
	0.190	0.354	0.815	1.506	2.777	3.964	5.266	7.245
	0.255	0.473	1.082	1.996	3.681	5.238	6.959	9.564
8.0	0.062	0.122	0.286	0.546	1.033	1.501	1.996	2.814
	0.150	0.283	0.643	1.200	2.217	3.177	4.221	5.818
	0.201	0.379	0.869	1.628	3.010	4.315	5.736	7.928
	0.269	0.510	1.155	2.163	3.989	5.716	7.596	10.476

Table 2.10-I. Peak Flows (Q) from a Watershed (ft^3/s), Runoff Curve Number 90

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	1.8	3.3	7.5	13.9	25.5	36.4	48.3	66.4
	3.7	6.8	15.0	27.3	49.2	69.3	92.0	124.2
	5.0	9.3	20.5	37.3	67.4	95.1	126.3	170.8
	6.7	12.2	27.1	49.1	88.7	125.1	166.1	224.4
0.5	1.9	3.5	8.1	15.0	27.7	39.7	52.7	72.8
	4.0	7.4	16.5	30.1	54.5	77.1	102.3	138.7
	5.5	10.1	22.5	41.1	74.5	105.5	140.0	190.2
	7.2	13.4	29.7	54.2	98.3	138.9	184.4	250.2
1.0	2.0	3.7	8.6	16.4	30.0	43.0	57.1	79.3
	4.3	8.0	18.1	33.8	60.2	85.2	113.2	154.1
	5.9	10.9	24.5	46.1	82.1	116.5	154.7	211.0
	7.8	14.5	32.5	60.9	108.4	153.5	203.9	277.8
2.0	2.1	3.9	9.1	17.2	32.2	46.3	61.6	85.9
	4.6	8.7	19.6	36.1	66.1	93.8	124.6	170.4
	6.3	11.8	26.6	49.1	90.0	128.0	170.0	233.0
	8.4	15.6	35.2	65.0	119.0	168.9	224.4	307.1
4.0	2.1	4.1	9.7	18.3	34.4	49.7	66.1	92.7
	5.0	9.3	21.2	39.1	72.2	102.8	136.6	187.6
	6.7	12.5	28.8	53.2	98.1	140.0	186.0	255.9
	9.0	16.7	38.2	70.5	130.0	185.0	245.8	337.8
8.0	2.2	4.3	10.1	19.3	36.5	53.0	70.5	99.4
	5.3	10.0	22.7	42.4	78.3	112.2	149.1	205.5
	7.1	13.4	30.7	57.5	106.3	152.4	202.6	280.0
	9.5	18.0	40.8	76.4	140.9	201.9	268.3	370.0

Table 2.11-M. Peak Flows (Q) from a Watershed (m^3/s), Runoff Curve Number 95

Q2 – watershed peak flow for a 2-year storm (m^3/s)
Q5 – watershed peak flow for a 5-year storm (m^3/s)
Q10 – watershed peak flow for a 10-year storm (m^3/s)
Q25 – watershed peak flow for a 25-year storm (m^3/s)

Average Grade (%)	Watershed Area (ha)							
	2	4	10	20	40	60	80	120
0.25	0.110	0.201	0.433	0.767	1.362	1.900	2.407	3.349
	0.204	0.357	0.753	1.322	2.310	3.199	4.029	5.569
	0.252	0.447	0.948	1.670	2.933	4.069	5.133	7.115
	0.311	0.552	1.178	2.075	3.647	5.065	6.390	8.862
0.5	0.125	0.224	0.484	0.864	1.537	2.149	2.724	3.800
	0.227	0.405	0.858	1.506	2.642	3.669	4.618	6.401
	0.283	0.501	1.073	1.897	3.338	4.643	5.864	8.137
	0.348	0.623	1.331	2.353	4.148	5.770	7.293	10.130
1.0	0.136	0.246	0.541	0.965	1.727	2.424	3.072	4.298
	0.252	0.456	0.971	1.716	3.010	4.193	5.286	7.336
	0.311	0.563	1.203	2.146	3.791	5.280	6.676	9.284
	0.385	0.699	1.492	2.664	4.706	6.557	8.296	11.540
2.0	0.150	0.275	0.597	1.079	1.931	2.718	3.454	4.844
	0.286	0.504	1.099	1.942	3.431	4.776	6.019	8.386
	0.351	0.623	1.362	2.407	4.295	5.977	7.582	10.561
	0.433	0.773	1.687	2.984	5.326	7.412	9.414	13.114
4.0	0.164	0.297	0.663	1.195	2.160	3.038	3.865	5.439
	0.320	0.575	1.220	2.194	3.882	5.405	6.860	9.550
	0.391	0.699	1.512	2.724	4.816	6.767	8.587	11.954
	0.484	0.864	1.874	3.372	5.968	8.392	10.651	14.827
8.0	0.178	0.326	0.725	1.325	2.387	3.378	4.318	6.073
	0.351	0.640	1.379	2.441	4.388	6.141	7.763	10.813
	0.428	0.781	1.682	3.027	5.445	7.616	9.629	13.533
	0.529	0.965	2.078	3.749	6.744	9.434	11.934	16.784

Table 2.11-I. Peak Flows(Q) from a Watershed (ft^3/s), Runoff Curve Number 95

Q2 – watershed peak flow for a 2-year storm (ft^3/s)
Q5 – watershed peak flow for a 5-year storm (ft^3/s)
Q10 – watershed peak flow for a 10-year storm (ft^3/s)
Q25 – watershed peak flow for a 25-year storm (ft^3/s)

Average Grade (%)	Watershed Area (ac)							
	5	10	25	50	100	150	200	300
0.25	3.9	7.1	15.3	27.1	48.1	67.1	85.0	118.3
	7.2	12.6	26.6	46.7	81.6	113.0	142.3	196.7
	8.9	15.8	33.5	59.0	103.6	143.7	181.3	251.3
	11.0	19.5	41.6	73.3	128.8	178.9	225.7	313.0
0.5	4.4	7.9	17.1	30.5	54.3	75.9	96.2	134.2
	8.0	14.3	30.3	53.2	93.3	129.6	163.1	226.1
	10.0	17.7	37.9	67.0	117.9	164.0	207.1	287.4
	12.3	22.0	47.0	83.1	146.5	203.8	257.6	357.8
1.0	4.8	8.7	19.1	34.1	61.0	85.6	108.5	151.8
	8.9	16.1	34.3	60.6	106.3	148.1	186.7	259.1
	11.0	19.9	42.5	75.8	133.9	186.5	235.8	327.9
	13.6	24.7	52.7	94.1	166.2	231.6	293.0	407.6
2.0	5.3	9.7	21.1	38.1	68.2	96.0	122.0	171.1
	10.1	17.8	38.8	68.6	121.2	168.7	212.6	296.2
	12.4	22.0	48.1	85.0	151.7	211.1	267.8	373.0
	15.3	27.3	59.6	105.4	188.1	261.8	332.5	463.2
4.0	5.8	10.5	23.4	42.2	76.3	107.3	136.5	192.1
	11.3	20.3	43.1	77.5	137.1	190.9	242.3	337.3
	13.8	24.7	53.4	96.2	170.1	239.0	303.3	422.2
	17.1	30.5	66.2	119.1	210.8	296.4	376.2	523.7
8.0	6.3	11.5	25.6	46.8	84.3	119.3	152.5	214.5
	12.4	22.6	48.7	86.2	155.0	216.9	274.2	381.9
	15.1	27.6	59.4	106.9	192.3	269.0	340.1	478.0
	18.7	34.1	73.4	132.4	238.2	333.2	421.5	592.8

2.4 Choosing the Correct Solution

Choosing the correct solution for a farm water erosion problem requires a considerable amount of thought. The contractor and/or designer must fully diagnose the problem before arriving at an acceptable solution. In the problem diagnosis, the type of erosion occurring at the site must first be addressed. Generally, erosion can be categorized into the three types.

Sheet Erosion – is soil movement resulting from raindrop splash and surface runoff, and occurs uniformly over the slope.

Rill and Gully Erosion – occurs when surface water concentrates in flows across farmland, resulting in the formation of well-defined channels. These channels are called rills when they are small enough not to interfere with tillage operations and gullies when they can't be smoothed by normal tillage operations.

Ditch Bank Erosion – is thell breakdown of the ditch bank due to surface runoff, soil instability, bank seepage, the flow of water in the ditch, or land management practices.

Table 2.12 lists possible solutions to consider for each type of erosion. Consider the solutions in the order they appear, which reflects an increasingly severe problem. For sheet and rill/gully erosion, always consider land management practices and subsurface drainage first. If the problem is severe, a structural control will also be required to arrive at an adequate overall solution.

Table 2.12. Choosing the Correct Solution

Problem – Sheet Erosion

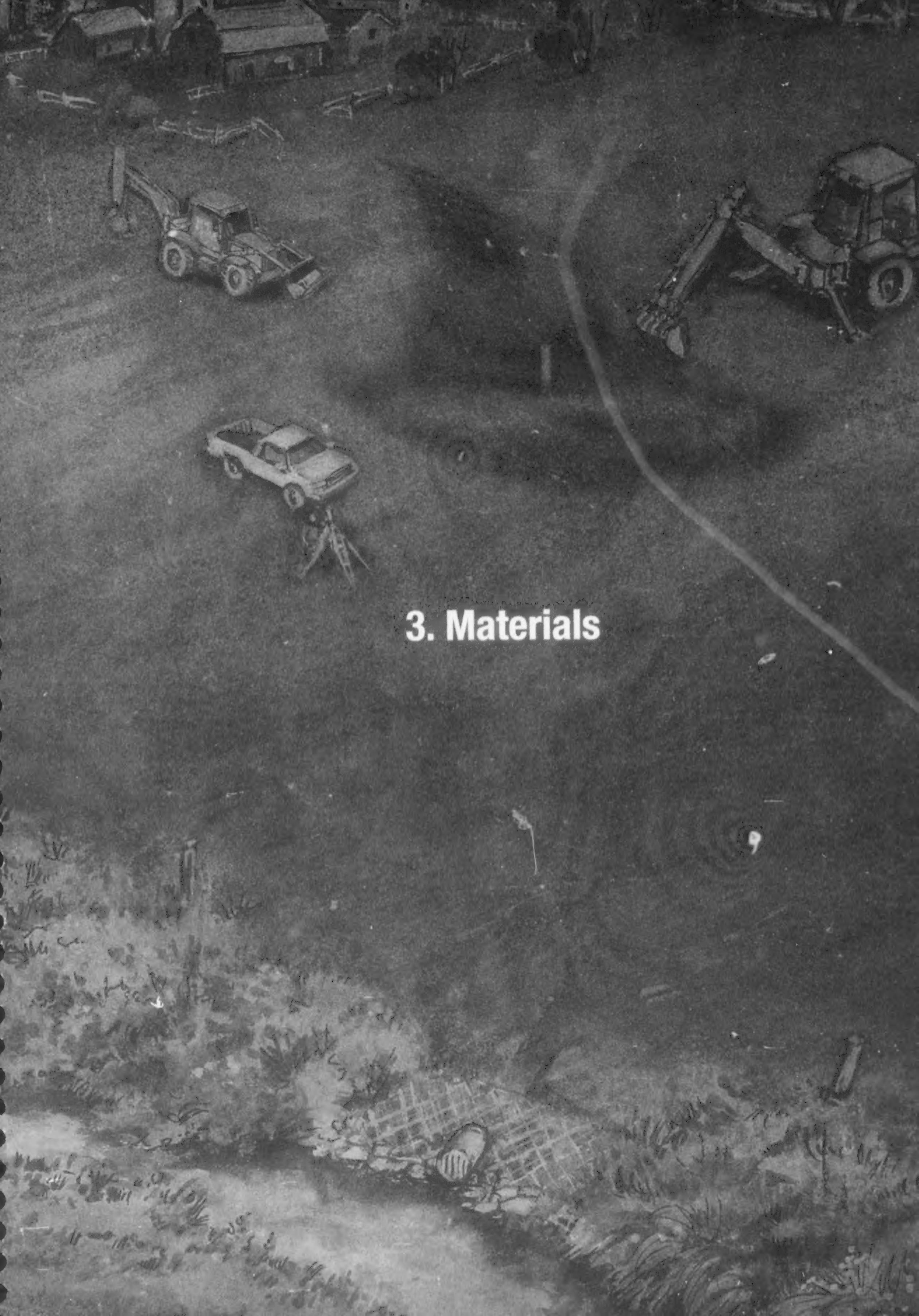
Solution	Conditions Where Applicable	Manual Section
1. Cropping and tillage program	• Uniform steep land slopes	1.2.1 Factors Affecting Soil Erosion by Water
2. Subsurface drainage	• Heavy soil with poor underdrainage	1.2.1 Factors Affecting Soil Erosion by Water
3. Field terracing	• Uniform slopes • Highly productive soils	4.5 Water and Sediment Control Basins

Problem – Rill/Gully Erosion

Solution	Conditions Where Applicable	Manual Section
1. Cropping and tillage program	• Steeply sloping lands • Soil with low water absorption ability	1.2.1 Factors Affecting Soil Erosion by Water
2. Subsurface drainage	• Heavy soil with poor underdrainage	1.2.1 Factors Affecting Soil Erosion by Water
3. Field terracing	• Uniform slopes • Highly productive soils	4.5 Water and Sediment Control Basins
4. Surface water inlet and tile line without/with water storage, ie. WASCoB	• <20 ha (<50 ac) watershed	4.3.2 Drop Pipe Inlets 4.5 Water and Sediment Control Basins
5. Grassed waterway with surface water inlet and tile line	• ≥20 ha (≥50 ac) watershed • Grade 1% to 5%	4.1.1 Grassed Waterways
6. Open ditch with vegetated banks sloped at 2.0 horizontal: 1.0 vertical	• Grade <1%	4.1.2 Open Ditches
7. Grassed waterway with surface water inlet and tile line and drop structures	• ≥20 ha (≥50 ac) watershed • Grade 1% to 5%	4.1.1 Grassed Waterways 4.3 Drop Structures
8. Lined waterway e.g. rock riprap, gabion mattress, interlocking blocks	• Grade 10% to 30%	4.1.1 Grassed Waterways 4.1.2 Open Ditches
9a. Drop structures – grade control structures	For gabion basket type: • <1 m (<3 ft) vertical drop • <4.25 m^3/s (<150 ft^3/s) flow For log type: • <0.6 m (<2 ft) vertical drop • <1.7 m^3/s (<60 ft^3/s) flow	4.3.3 Grade Control Structures
9b. Drop structures – chute spillways	• <1.5 m (<5 ft) vertical drop • <2.8 m^3/s (<100 ft^3/s) flow	4.3.1 Chute Spillways
9c. Drop structures – drop pipe inlets	• <3 m (<10 ft) vertical drop • >20% grade • <0.4 m^3/s (<15 ft^3/s) flow per drop pipe inlet	4.3.2 Drop Pipe Inlets

Problem – Ditch Bank Erosion

Solution	Conditions Where Applicable	Manual Section
1. Grade side-slopes at 2 horizontal:1 vertical	• Sloughing banks due to steepness	4.1.2 Open Ditches
2. Vegetate banks	• Sloughing banks	
3. Berms and buffer strips	• Excess runoff over ditch banks	
4. Drop structures in banks	• Concentrated flow of runoff over banks	
5. Riprap channel bank curves	• Localized scouring due to flow in ditch	
6. Riprap channel bottom	• High flow velocity due to steep ditch bottom grades	
7. Drop structures in ditch bottom	• High flow velocity due to steep ditch bottom grades	
8. Proper tile drainage outfalls on ditch bank	• Erosion at tile outfalls on ditch bank	



3. Materials

3. Materials

Most erosion control projects require some additional materials delivered to the job site. These materials may be as simple as a properly selected grass-seed mixture or as complicated as a pre-engineered, prefabricated, steel or plastic drop structure. In general, erosion control measures include materials, which perform one or more of the following functions:

- reduce the impact of raindrops, which can dislodge soil particles from exposed soil
- bind soil particles together
- prevent uncontrolled flows down steep slopes
- reduce the velocity of sheet and channel flows
- provide protection to the soil so potentially erosive flows do not cause damage

The materials discussed in this section are organized into the following categories:

- vegetative cover
- rock riprap
- geotextiles
- precast, prefabricated and proprietary materials

3.1 Vegetative Cover

Vegetative cover is the most common, most widely used and least expensive erosion control measure. Vegetative cover reduces the impact of the raindrop on exposed soil and binds soil particles together through its root system. With these functions in mind, a good vegetative cover includes plant species with a thick canopy of growth above the ground surface and a dense, fibrous root system below ground. Trees and shrubs are used in special circumstances, but vegetative cover most often refers to grasses, legumes or grass-legume mixtures.

Where is Vegetative Cover Required?

Most erosion control projects involve some type of excavation or earth moving operation, resulting in the exposed soil being susceptible to the erosive forces of wind and water. The degree and type of protection used depends on the severity of the problem that could result if protection were not provided.

Vegetative cover provides good protection once it is established. Typical areas where vegetative covers are used include:

- open channel banks
- grassed waterways, buffer strips and water and sediment control basins (WASCoBs)
- steep slopes and specific areas susceptible to erosion within construction sites

Establishing Vegetative Cover

There are six common methods of establishing vegetative cover:

- seeding using agricultural methods
- surface seeding alone
- surface seeding with straw mulch
- surface seeding with hydraulic mulch
- seeding in conjunction with an erosion control blanket
- sodding

The method used to establish vegetative cover depends on how fast the cover needs to be established. All of the above methods have their place and advantages. Table 3.1 lists these methods, provides comments pertaining to each method and lists situations where the method is more commonly used. The first two methods – seeding using agricultural methods and surface seeding alone – are the most common methods applied in agricultural erosion control projects.

Table 3.1. Establishment Methods for Vegetative Covers

Method	Comments	Uses
Seeding using agricultural methods	• Inexpensive • Reliable • Seed can be broadcast by hand or by machine and may be incorporated	• Grassed waterways, buffer strips, terraces • Areas where farm tillage and planting equipment can operate
Surface seeding alone	• Inexpensive • Establishment is very dependent on weather	• Ditch banks • Steep slopes on construction sites where quick cover is not imperative
Surface seeding with straw mulch	• Requires specialized equipment and materials • More expensive • More labour intensive • Very reliable • Straw mulch properly applied will provide ideal conditions for seed germination as well as provide a degree of immediate soil protection	• Erosion sites where immediate cover is needed to provide a small amount of protection • Erosion sites that require seeding during dry periods of the year
Surface seeding with hydraulic mulch	• More expensive • Very reliable if applied in early spring or early fall • See Appendix D for a list of companies that hydroseed	• Erosion sites where vegetative establishment is difficult • Long steep slopes, berms and emergency spillways where direct access with agricultural equipment is impossible
Seeding with erosion control blanket	• Commercial prefabricated layer of material composed of wood shavings, straw, coir (coconut), or other material which may or may not also contain seed mixture • Very costly • Very effective • Provides immediate protection	• Very effective on long damp slippery slopes or dry sandy slopes • Use on steep slopes or areas where immediate protection is essential
Sodding	• Very costly • Initial maintenance cost is higher due to watering requirements • Sod has a tendency to slide down long, steep, damp or clayey slopes even when staked • Roots of sod are generally shallower than those of seeded turf	• Areas where immediate good appearance is necessary

Table 3.2 describes a general seed mixture that's recommended for a majority of agricultural-related erosion control projects.

General Comments

- Across Ontario there may be some locally preferred seed mixtures that work very well and are inexpensive.
- For all erosion control projects, apply seed daily immediately following construction while soil is moist, if possible.
- For best results, use normal farm methods of seed establishment where areas to be seeded are accessible to farm machinery. Otherwise, broadcast by hand, all-terrain vehicle or other means and incorporate by harrowing or cultipacking.
- When seeding grassed waterways, consider using a seed mixture that complements the use of the adjoining field. For example, if the adjacent field is a hay field, choose a mixture for the waterway that could also be harvested as a suitable hay crop.
- Fertilization is important in seed establishment. A general recommendation for most sites is to broadcast and lightly incorporate 80 kg/ha (70 lb/ac) of 7-7-7.
- A simple method to mulch a newly seeded site is to broadcast straw by hand or flail it using a solid manure spreader. A minimum rate of 1,000 kg/ha (900 lb/ac) of straw is recommended. The straw should be crimped lightly into the soil using discs. On smaller projects, crimp the straw manually using shovels.

Table 3.2. A General Purpose Erosion Control Seed Mixture

Components	Percent of Mixture	Comments
Creeping red fescue	50%	• Fertilization recommended • Daily seeding recommended • Early spring, late summer or early fall seeding preferred • Clip once or twice per year along with periodic fertilization to maintain stand • Future maintenance should preclude use of herbicides • Can be sprayed with selective herbicides
Perennial ryegrass	45%	• Quick to establish • Drought resistant • Susceptible to herbicide damage • Fertilization recommended • Daily seeding recommended • Early spring, late summer or early fall seeding preferred • Clip once or twice per year to maintain stand
White clover (low growing type)	5%	• Fertilization not necessary • Daily seeding recommended • Early spring or early fall seeding preferred • Trefoil seed must be inoculated, coated seed is recommended • Susceptible to herbicide damage

Note: A nurse crop is recommended with all seeding – a small grain such as winter wheat, rye, barley, oats, mixed grain or other equivalent seed applied at 80 kg/ha (70 lb/ac).

3.2 Rock Riprap

Rock riprap is the most common material used in areas susceptible to erosion that require more protection than vegetative cover alone. Rock riprap has many farm applications as a lining material. Contractors should be familiar with basic design elements to ensure they know the proper rock riprap to choose for the job and where to use it.

Rock riprap is most often used to provide an armoured coating that withstands, without damage, the forces water puts on it. A secondary use is to actually dissipate the energy from flowing water as it passes through the rock riprap, releasing it in a more tranquil state to avoid downstream damage. This second aspect of rock riprap has limited application on farm-scale problems contractors are typically asked to solve.

Some Advantages of Rock Riprap

- Full protection at installation, unlike vegetative cover which requires an establishment period.
- Flexibility to move as the ground under it settles or heaves, providing a self-healing quality.
- Porous structure, enabling water to move freely through it in either direction, circumventing the possibility of hydraulic pressures building up on one side or another.
- Natural appearance that's usually esthetically pleasing.
- Probably the most economically viable material for the protection provided, beyond simple vegetative cover. If transportation costs or availability make rock riprap uneconomical, consider other methods.

Uses of Rock Riprap

Rock riprap has many applications for on-farm erosion prevention, and the most common include:

- sharp bends in streams and ditches
- lining material in watercourses to prevent scouring
- lining material in watercourses to prevent sloughing
- ends of culverts
- rock chutes
- gabion baskets
- low level stream or ditch crossings
- grade control structures or as protection in areas of rapid grade change along grassed waterways or ditches
- tile outlets, inlets and outlets of drop structures

Special design considerations are required for each of the uses listed. Some of these considerations will be covered in more detail in Section 4. Additional information is provided in the OMAFRA Factsheet, *Use of Rock in Erosion Control Projects,* Order No. 90-227.

Rock Riprap Design Considerations

A number of factors must be considered when choosing the type of rock riprap for a particular job. Some factors relate to the rock riprap itself – such as its size, shape and weight. Other factors consider the forces exerted on the rock riprap – such as velocity or volume of water flows.

Rock Riprap Size – Rock riprap is obtained through a quarrying process and normally sorted according to its rough diameter. One or more quarrying operations – including blasting, crushing and screening – may be used to obtain a certain size of stone. Many Ontario quarries offer stone in 50 mm (2 in.) gradients ranging from 50-250 mm (2-10 in.) in size. Table 3.3 outlines the products a typical Ontario quarry offers for sale. The quarrying business uses several terms to describe these products.

- Minus or crusher run – rock riprap or stone that's passed through a certain size of screen or has exited from a crusher with a certain setting. All of the fines are included with the maximum allowable size. Of the two types of primary crushers – the "jaw crusher" and "impact (impeller) crusher" – the latter tends to produce a product with a higher percentage of fines. This fact is important since fines are more erodible than the accompanying rock riprap.
- Clear – stone or rock riprap that's gone through the screening plant to remove stone bigger or smaller than a certain specified size. For example, 100 mm (4 in.) clear has all the fines removed up to a certain tolerable range.
- Gabion stone – a special type of rock riprap used to fill gabion baskets or gabion mats that's available at most quarries. Gabion stone is rock riprap in the 100 mm (4 in.) to 200 mm (8 in.) size range. This stone has gone through the screening plant and passed through a 200 mm (8 in.) screen but passed over a 100 mm (4 in.) screen.
- Blast rock or shot rock – material as it has been blasted from the face of the quarry. Rock riprap of all sizes is present from very small particles to huge chunks. The average size of the particles of blast rock varies depending on the drill pattern of the blast. Blast rock is one of the most common erosion protection materials – it's less expensive than stone which has been processed through crushing and screening operations.
- Armour rock – results from the direct blasting of the quarry face. This term refers to the exceptionally large chunks varying in size from 0.6-2 m (2-6 ft) and larger. Armour rock is normally hand picked by a contractor because of its size or shape to do a specific job. For example a contractor may choose large square stones that will fit well together to form the endwall of a culvert.

Rock Riprap Weight – A correlation between rock riprap size and weight is often necessary. Areas of erosion protection, where impact from floating debris is a problem, require consideration of the weight of the individual pieces of riprap. Ice is a common floating debris problem in Ontario.

As an example, limestone riprap – the most common in Ontario – has a density of around 2,400 kg/m^3 (150 lb/ft^3). Rock riprap by the truckload, which naturally will include voids, has an approximate weight of 1,600 kg/m^3 (1.35 tons/yd^3 or 100 lb/ft^3). A contractor must understand this relationship as contracts often specify a certain number of cubic metres or cubic yards but sell rock riprap by the tonne or ton.

Rock Riprap Shape – Most rocks and stones used in erosion projects are angular or jagged in shape. This feature allows individual pieces to knit together or interlock so the rock riprap protection acts as a complete system. Rounded stones commonly found in farm fields don't have this quality and are not as effective in most erosion control projects.

Rock Riprap Gradation – For most applications of rock riprap, a proper gradation of sizes is important. There should be enough large heavy stones to resist the forces of floating ice and debris, and enough smaller sizes to fill the voids. A common method of specifying gradation is to refer to the median stone diameter or d_{50}. For example, if a median stone diameter, d_{50} = 200 mm (8 in.), is specified, then 50% of the total weight will have a size greater than 200 mm (8 in.) diameter and 50% of the total weight will have a size smaller than 200 mm (8 in.) diameter. For rock riprap purposes, there are ideal limits on the quantity and size of stone above and below the median stone diameter. Table 3.4 shows the ideal gradation of rock riprap and indicates, for example, that if 200 mm (8 in.) diameter rock riprap weighs 16 kg (35 lb), then the maximum size of rock riprap should be 3K or 3 x 16 = 48 kg (105 lb). Table 3.4 also indicates that ideally 20% of the rock riprap should have a weight in the range of 2K to 3K or 32-48 kg (70-105 lb). The OMAFRA Factsheet, *Use of Rock in Erosion Control Projects*, Order No. 90-227, further explains this concept.

To make the concept more useful to contractors and quarry operators, rock riprap size is specified based on the largest sized particles in it. This designation is referred to as the d_{100} of the rock riprap.

Table 3.3. Products of Typical Quarries

Name of Product	Comments or Possible Uses
Clear stone	
9.5 mm (⅜ in.)	
12.5 mm (½ in.)	
19 mm (¾ in.) open graded crushed rock	100% passes 19 mm (¾ in.) sieve 100% retained on 16 mm (⅝ in.) sieve
25 mm (1 in.)	
19 mm (¾ in.) field bed stone	
37.5 mm (1½ in.) field bed stone	
50-100 mm (2-4 in.) quarry stone	Bank protection
150 mm (6 in.) crushed rock	100% passes 150 mm (6 in.) sieve No more than 10% passing 75 mm (3 in.) sieve
75-200 mm (3-8 in.) gabion stone	Gabion baskets or bank protection
Crusher run (stones with fines)	
Granular A	37.5 mm (1½ in.) minus
Granular B	100 mm (4 in.) minus
Granular C	150 mm (6 in.) minus
Stone dust	
Other	
Blast rock	Riprap in channels, rock chutes
Armour rock	Endwall protection for culverts

Table 3.4. Ideal Gradation of Rock Riprap

Size of Stone	Percentage of Total Weight Smaller than the Given Size
3K*	100
2K	80
K	50
0.1K	10

*K = the specified d_{50} size

Water Velocity in Waterway – To prevent flowing water from moving the installed rock riprap, consider the water velocities experienced by the channel to be protected with rock riprap. Larger rock riprap sizes can withstand higher velocities before they start to move under the force of the water flow. The velocity of the water in a ditch or waterway is a function of the slope, roughness and shape of the channel. If the velocity of water in a channel can be determined, charts are available to relate velocity to appropriate rock riprap size. Manning's equation is most often used to estimate water flow velocity in a drainage channel.

Manning's equation

Metric:	Imperial:
$V = \frac{R^{2/3} S^{1/2}}{n}$	$V = \frac{1.486\, R^{2/3} S^{1/2}}{n}$
V = velocity in m/s	V = velocity in ft/s
n = coefficient of roughness	n = coefficient of roughness
R = hydraulic radius in m	R = hydraulic radius in ft
S = slope in m/m	S = slope in ft/ft

The hydraulic radius (R) and the coefficient of roughness (n) are variables in this formula that require further explanation. To obtain the hydraulic radius (R), the geometry of the channel and the depth of water that flows in it must be known. Hydraulic radius is obtained by dividing the cross-sectional area of the flow by the channel's wetted perimeter. Figure 3.1 shows the wetted perimeter (P) and cross-sectional area (A) of a typical trapezoidal ditch cross-section.

Figure 3.2 gives the formulae to calculate top width (T), cross-section area (A), wetted perimeter (P) and hydraulic radius (R) of some different channel shapes. The coefficient of roughness (n) of a channel refers to the friction that resists the flow. For example, smooth earthen banks have less friction than rough rock banks. If rock riprap protection is applied periodically along the channel – as would happen when protecting bends or specific washouts – choose a value of n equal to 0.03. If a complete channel is to be lined with rock riprap, use an n value of approximately 0.04.

Figure 3.3-M (3.3-I) is a nomograph used to determine flow velocity if coefficient of roughness (n), hydraulic radius (R) and slope (S) are known. The velocity determined from this nomograph is used to calculate the required size of rock riprap in straight sections of channel where a uniform[1] type of flow is expected.

Figure 3.4-M (3.4-I) – the Isbash curve – is used to choose a size of rock riprap if the velocity is known. If it's expected that debris impact on the rock riprap would be a serious problem, double the size of stone obtained from this chart.

Channel bends require greater protection than straight sections. The size of stone obtained from Figure 3.4-M (3.4-I), if multiplied by a factor of 1.5, will identify a size of stone sufficient to withstand these extra forces.

[1] Open channel flow is said to be uniform flow if the discharge and the water depth at any section in the reach do not change within the time period of interest.

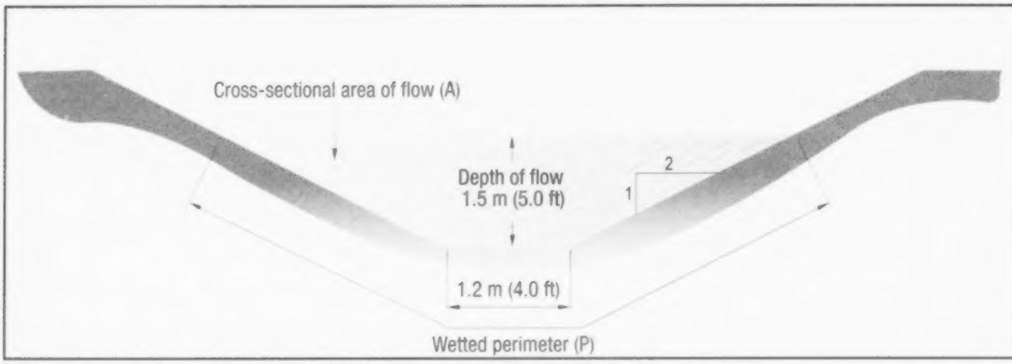


Figure 3.1. Relationship Between Wetted Perimeter and Cross-sectional Area of Flow

Section	Area A	Wetted Perimeter P	Hydraulic Radius R	Top Width T
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\dfrac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Trapezoid	$bd + zd^2$	$b + 2d\sqrt{z^2+1}$	$\dfrac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b + 2zd$
 Rectangle	bd	$b + 2d$	$\dfrac{bd}{b+2d}$	b
 Parabola	$\dfrac{2Td}{3}$	$T + \dfrac{8}{3}\dfrac{d^2}{T}$	$\dfrac{2T^2d}{3T^2+8d^2}$	$\dfrac{3}{2}\dfrac{A}{d}$

Figure 3.2. Formulae to Calculate Cross-sectional Area, Wetted Perimeter, Hydraulic Radius and Top Width

Figure 3.3-M. Nomograph to Solve Manning's Equation

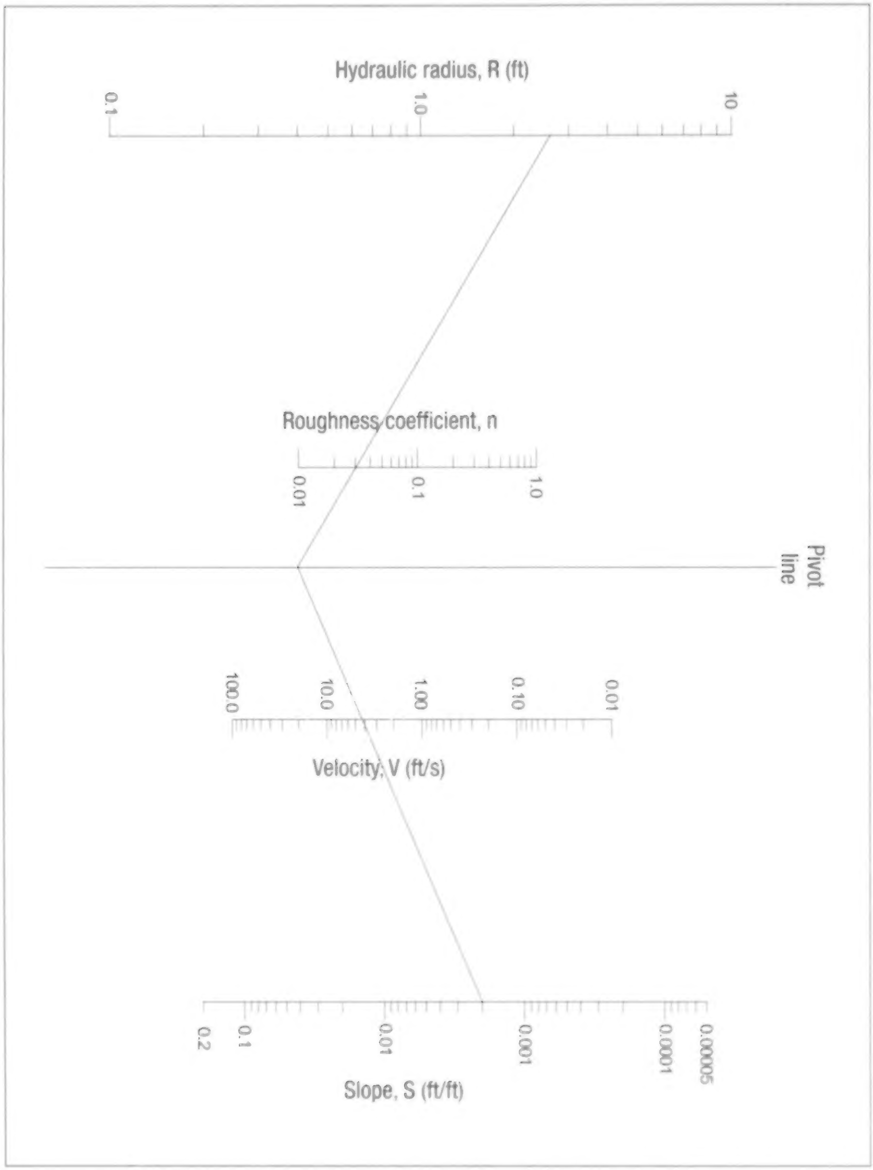


Figure 3.3-I. Nomograph to Solve Manning's Equation

$$V = \frac{1.486\,R^{2/3}S^{1/2}}{n}$$

R = 2.66 ft
n = 0.03
S = 0.002 ft/ft
Read V = 4.3 ft/s

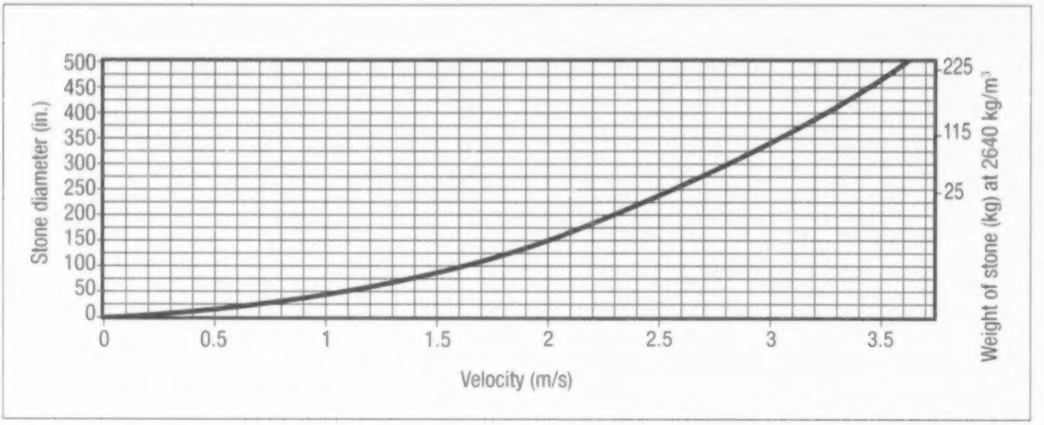


Figure 3.4-M. The Isbash Curve to Calculate Rock Riprap Size

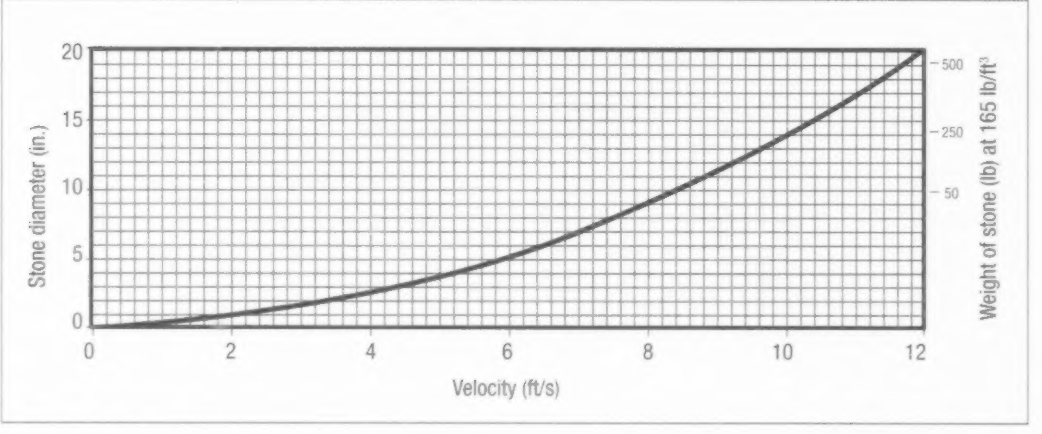


Figure 3.4-I. The Isbash Curve to Calculate Rock Riprap Size

Depth of Flow – The depth of flow is also used to estimate rock riprap size. The charts used for this method are perhaps more accurate because they consider both the water velocity force on the rock riprap and the forces due to the weight of the water or "tractive force." Figure 3.5 is a graph relating depth of flow to required rock riprap size. Keep in mind the ideal gradation of rock below the d_{100} size. The d_{100} designation in many ways is equivalent to ordering rock riprap using the 'minus' concept (e.g. d_{100} = 125 mm (5 in.) is approximately equal to 125 mm (5 in.) minus).

The answers obtained from Figure 3.5 are slightly more conservative than those obtained from Figure 3.4-M (3.4-I). For simplicity, and an additional degree of safety, use the methodology of Figure 3.5. When choosing a stone size for 90° bends, remember to multiply the size obtained from Figure 3.5 by a factor of 1.5. If debris impact on the rock riprap is expected, double the size of stone.

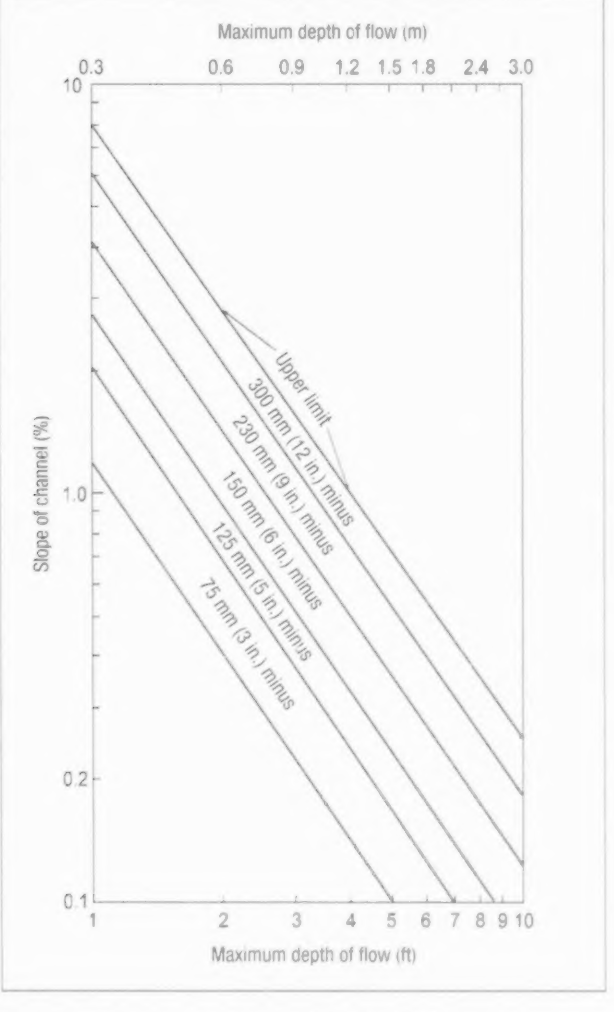


Figure 3.5. Chart to Determine Rock Riprap Size Knowing the Depth of Flow

General Recommendations on Choosing and Placing Rock Riprap

Filter Material – This can be made of properly graded sand or gravel, or more commonly a properly selected geotextile (see Section 3.3). Geotextile allows water to pass through it while holding fine particles of sand, silt or clay in place at the same time. It's common practice to place a geotextile below any rock riprap erosion control structure. Install geotextile so it precludes the possibility of water flowing under it rather than through it. This often means running the geotextile down and under the toe of the structure, as well as up the sides of an excavation.

Placement of Rock Riprap – Machine placed riprap is normally superior and less costly than hand placed riprap. If machine placing, don't drop rock riprap from a great distance or dump from a truck and let it roll down a bank – this can cause particles to separate. Place rock riprap with the bucket of an excavator or backhoe, starting at the bottom of a slope. Place the required thickness in one pass. If large individual pieces of rock riprap are required – for the ends of culverts – select individual pieces and then place to avoid large voids between rock riprap.

Thickness of Rock Riprap – To be effective, place rock riprap thick enough so it's considered to have layers. As a guide, use a thickness of 1.5-2 times the diameter of the largest particle, but ensure the thickness isn't less than 200 mm (8 in.). For example, if using rock riprap with a maximum stone size of 300 mm (12 in.), make the rock riprap at least 450 mm (18 in.) thick.

The Toe – The toe prevents rock riprap from sliding down the bank. Include a toe at the base of the slope for all rock riprap used for consistent streambank or slope protection. The toe should be at least as deep as the thickness of the rock riprap and about 1 m (3 ft) wide for small jobs.

Slope of Rock Riprap – Slope rock riprap at a minimum of 1.5 horizontal:1 vertical with a 2:1 slope being preferred. The recommended slope is an additional measure to prevent the movement or slipping of the rock riprap to the bottom of the slope.

Size of Rock Riprap – Contractors should now recognize the critical areas of riprap design. If special problems appear – extremely large or fast flows or extremely poor soil conditions – seek expert design advice. For most problems, the simplified design shown in this manual can be used. Further simplification is possible if blast or shot rock is considered to be of sufficient size for most of the small erosion control jobs encountered in agricultural settings. If blast rock is chosen, try to separate the large particles over 300 mm (12 in.). Also keep in mind the ideal gradation of materials described earlier.

Example Problem in Selection of Rock Riprap

An open ditch (n = 0.03) shows signs of severe scouring. The channel has a slope of 0.2%, is 1.52 m (5 ft) deep, 2:1 side slopes and a 1.22 m (4 ft) bottom. During the most severe floods, the channel flows full to the banks.

What would the velocity of flow be in the channel?

Solution – from Figure 3.2 the hydraulic radius of the channel is

Metric:

$$R = \frac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}} = \frac{(1.22 \times 1.52) + (2 \times 1.52^2)}{1.22 + (2 \times 1.52\sqrt{2^2 + 1})} = 0.81 \text{ m}$$

Imperial:

$$R = \frac{(4.0 \times 5.0) + (2 \times 5^2)}{4.0 + (2 \times 5\sqrt{2^2 + 1})} = 2.66 \text{ ft}$$

From Figure 3.3-M (3.3-I), knowing R = 0.81 m (2.66 ft), S = 0.2% or 0.002 m/m (ft/ft), n = 0.03, then velocity V = 1.3 m/s (4.3 ft/s).

What size of riprap could be used to repair a washout on a straight section of channel?

Solution (a) – Using Figure 3.4-M (3.4-I) and knowing V = 1.3 m/s (4.3 ft/s), a maximum stone size of 70 mm (2.8 in.) is obtained (see Figure 3.6-M (3.6-I)).

Solution (b) – Using Figure 3.5 and knowing a depth of flow of 1.52 m (5.0 ft), a required rock riprap size of 125 mm (5 in.) minus is obtained (see Figure 3.7).

Note: Solution (b) generally gives a more conservative answer and is the method normally used.

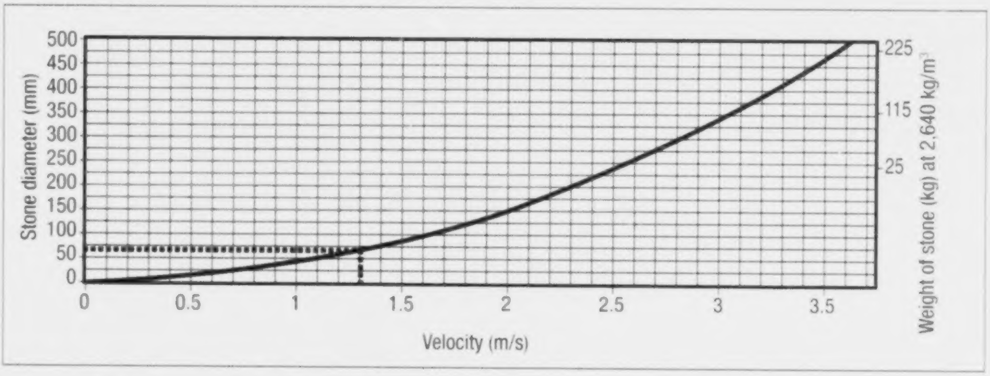


Figure 3.6-M. The Isbash Curve to Calculate Rock Riprap Size – Example Problem

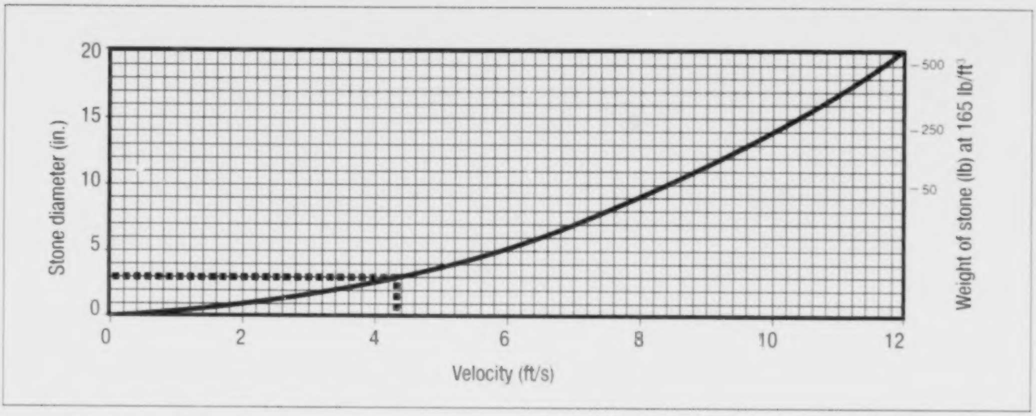


Figure 3.6-I The Isbash Curve to Calculate Rock Riprap Size – Example Problem

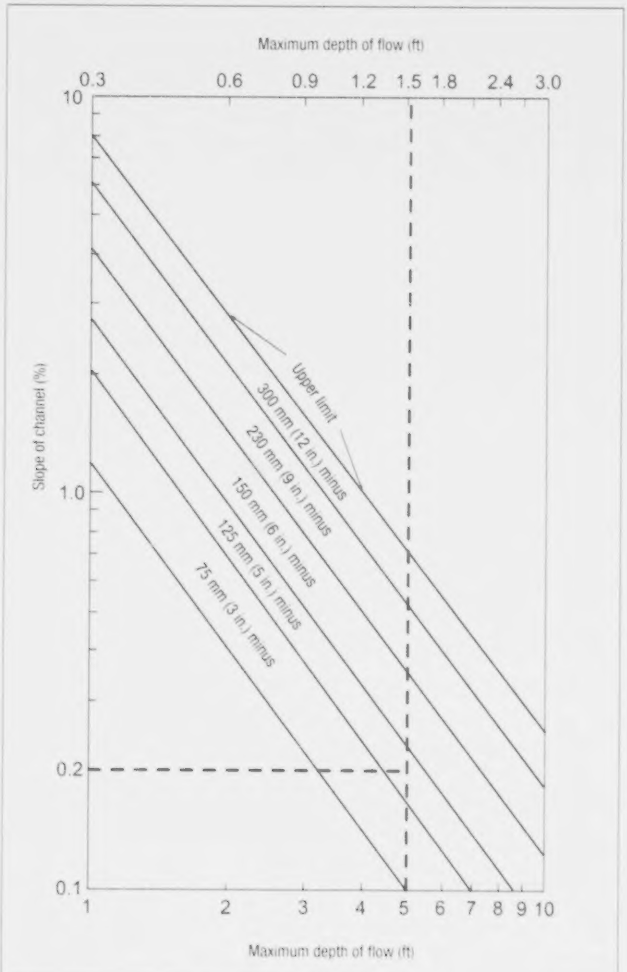
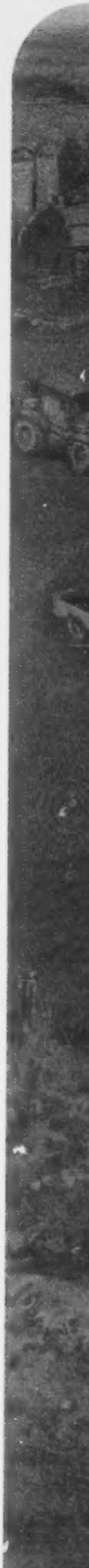


Figure 3.7. Chart to Determine Rock Riprap Size Knowing the Depth of Flow – Example Problem



3.3 Geotextiles

Geotextiles are synthetic products used in soil or soil-water related projects. These synthetic carpets or mats are constructed from a number of different fibres, using various additives and techniques, and are classified a number of ways.

Types of Geotextiles

Geotextiles are classified by the way they are manufactured as woven or non-woven.

Woven geotextiles

- lengthwise filaments or yarns interlaced with filaments or yarns arranged at right angles
- distinguished by the easily recognizable 90° weave pattern

Non-woven geotextiles

- produced by the bonding or interlocking of fibres by mechanical, chemical or thermal means
- recognizable by the lack of a specific pattern in the arrangement of individual filaments
- appearance is more closely associated to a blanket

Uses of Geotextiles

Geotextiles are further classified by how they are used.

Hydraulic uses

- situations when the geotextile is used in an environment with an important interplay between soil and water – typically the case with erosion control projects
- geotextile used in this environment has two main functions – filtration and drainage

Mechanical uses

- situations when the geotextile is used in an environment where soil or soil types are the single most important factor
- mechanical use of geotextile has to two functions – separation and reinforcement

Function of Geotextiles

Geotextiles serve four main functions – filtration, drainage, separation and reinforcement.

Filtration – This is an important property of geotextiles, particularly when used in a soil-water environment. The filtering property restricts the movement of soil particles out of a soil mass while allowing the free movement of water. Some typical applications where filtration is important include: French drains, subsurface agricultural drains and ditch bank stabilization under rock riprap. Geotextile properties to consider when filtration is important are pore opening size and permeability. Strength is also important, depending how the material will be handled. Non-woven fabrics normally have better filtration properties.

Drainage – Geotextiles perform a vertical drainage function within its own mass as well as a drainage function through the filter. This drainage function goes hand in hand with filtration. Drainage through the filter requires the same properties as those associated with filtration. If vertical drainage is important, the thickness of the geotextile becomes important in addition to its permeability and pore opening size. Non-woven fabrics normally have better drainage properties.

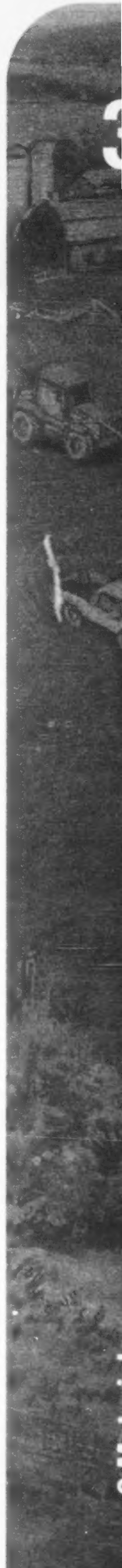
Separation – In a soil environment where drainage or filtration is not an important element, geotextiles serve an important role in physically separating different soil or aggregate types. Geotextiles are used in this capacity to separate different soil or aggregate types in road construction. The geotextile prevents the top layer from being punched into the lower layer or vice versa. This separation function is also effective when constructing a bed level type crossing. Pore size and strength, as well as permeability, are important considerations when choosing a geotextile for this purpose.

Reinforcement – The reinforcement function of a geotextile is analogous to the use of steel in reinforced concrete. The geotextile is the common factor connecting a mass of individual soil particles. In road construction, if the subgrade is of poor quality, the geotextiles will help distribute the load and increase the load-carrying capability of the finished roadway. For reinforcement purposes, the roughness of the geotextile becomes important just as the deformed bars in reinforced concrete are important. Tensile and burst strength are also important since the geotextile must transmit and withstand loads applied to it. Woven geotextiles can normally provide this function at less cost.

Specifying a Geotextile

Use the following steps to choose a proper geotextile.

1. Identify the primary function of the geotextile – filtration, drainage, reinforcement or separation. If applicable, identify the secondary function as well, i.e. filtration and drainage often go hand in hand.
2. Identify the strength of the geotextile required. The tensile strength may be important because of the method of placement or load it must transmit. The burst strength may be important because of the material to be placed over it. Manufacturers normally recommend the necessary strength, if construction and end use details are given.
3. Thickness should be specified if vertical drainage is the main criteria. Thickness is more likely influenced by other required properties such as strength.
4. The type of geotextile can be specified. Non-woven materials are normally preferred when drainage or filtration is required. Woven fabrics are often more economical for separation and reinforcement functions.
5. Geotextile material is important, especially if it's to be applied under water. Some geotextiles tend to sink, while others float. High permeability will assist in allowing a geotextile to sink to the bottom of an excavation.



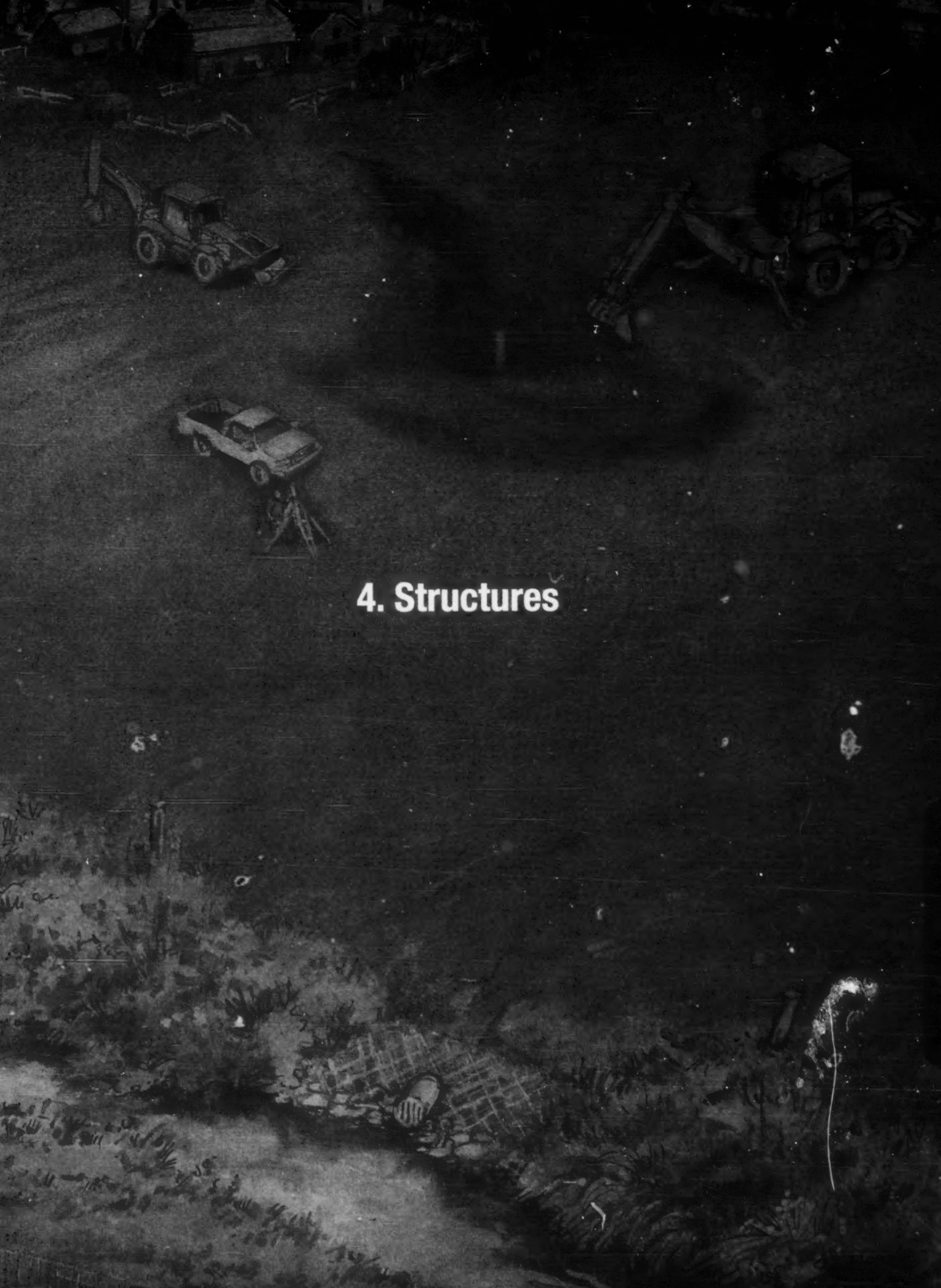
3.4 Precast, Prefabricated and Proprietary Materials

For many erosion control projects, prefabricated or precast materials made of concrete, plastic or steel may be available to help address the erosion problem. A number of manufacturers supply off-the-shelf materials in a variety of sizes to fit most needs. Installing these products requires varying amounts of field assembly. In other case, prefabrication is done according to certain hydraulic or structural specifications. Products that lend themselves to prefabrication include:

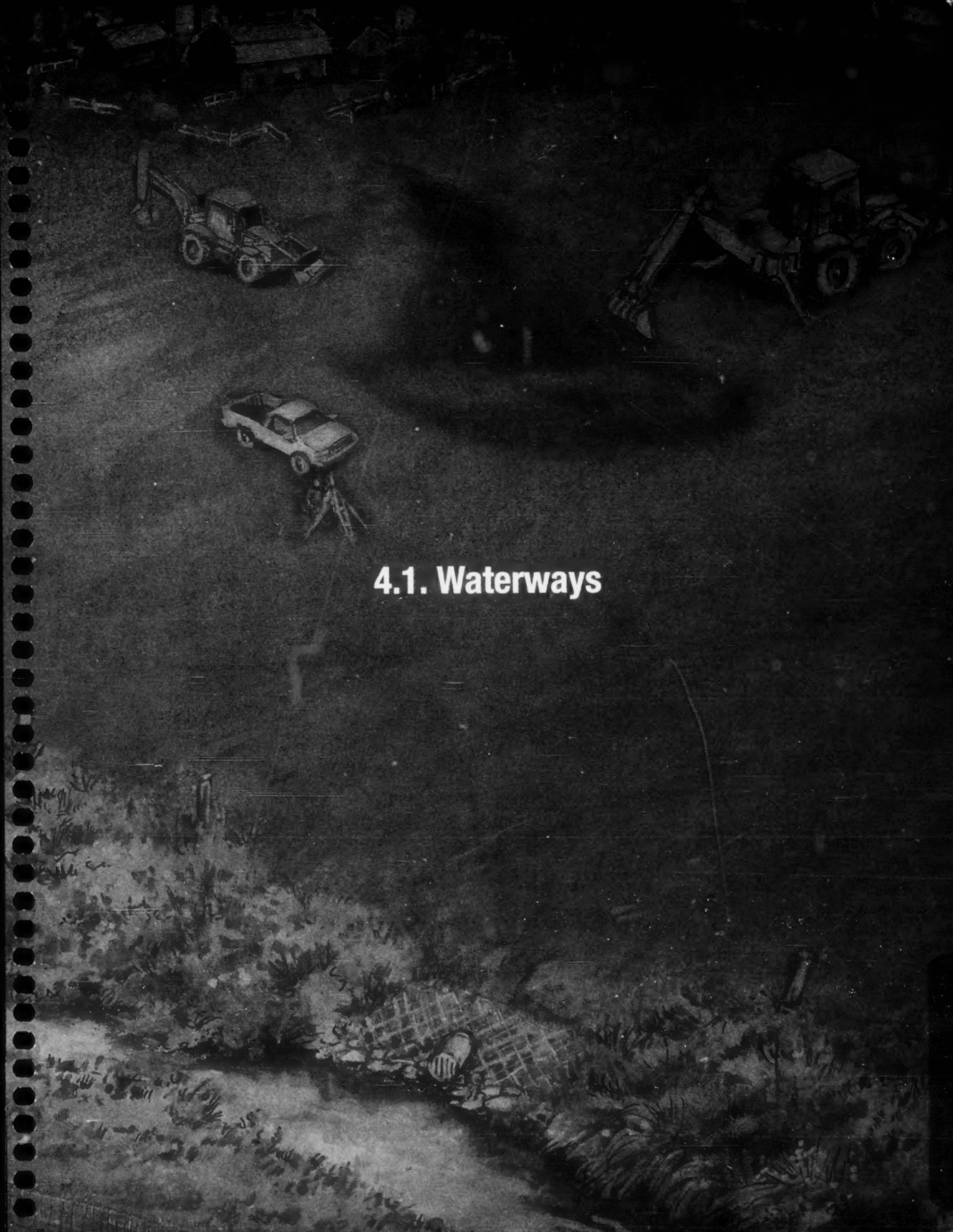
- catch basins
- coffer dams
- culverts
- drop pipe inlets
- erosion control blankets
- flexible fabric concrete forms
- gabion baskets and mats
- geogrids
- green gabions
- interlocking concrete blocks
- silt fences and floating silt curtains
- soil confinement systems
- surface water inlets
- coir fibre logs and mats
- tile drainage outfalls

A list of manufacturers and suppliers of these materials is provided in Appendix D.

4. Structures



4.1. Waterways



4. Structures

4.1 Waterways

4.1.1 Grassed Waterways

Grassed waterways are constructed to carry concentrated flows of surface water across cultivated farmland to a suitable outlet. These waterways effectively prevent gully erosion and are often constructed in natural depressions across fields where water collects and flows to an outlet. With the proper cross-section and grade for the waterway, and vegetative cover to limit flow velocities, a stable channel will handle the flow. Grassed waterways are effective in controlling erosion where surface water has caused severe rill damage. They also serve as outlet channels for contour strip cropping, contour diversions and as inlets to gully control structures.

Conditions where Applicable

Although grassed waterways are a good solution to field erosion caused by concentrated flows of water, examine other conservation measures closely before constructing a waterway. A good tillage and cropping program can reduce the peak rate of runoff from the land. In most cases, rill erosion created by runoff is corrected by a tillage and cropping program rather than by installing several grassed waterways. Providing a subsurface drainage system beneath the waterway, and throughout low lying wet areas of land around the waterway, can mean less surface water has to be carried off by the grassed waterway. Good conservation practices also result in less siltation of the waterway, as less sheet erosion occurs over the fields draining to the watercourse.

Grassed waterways are a feasible solution to a surface water problem if the contributing watershed is 20 ha (50 ac) or more in area. For smaller watersheds, first consider a water and sediment control basin (WASCoB) or a tile/surface water inlet system that may be more economical and much easier to work around with farm equipment.

Shape of Waterway

Vegetated waterways are constructed as parabolic or trapezoidal in cross-sectional shape. Parabolic waterways are the most common and generally the most satisfactory. The parabolic waterway is a broad, shallow, saucer-shaped channel with the bottom almost flat and 10 horizontal:1 vertical side slopes (Figure 4.1). This parabolic shape approximates natural channels – spreading the water, slowing its velocity and reducing its power to erode. A parabolic waterway also permits farm machinery to cross and allows for easy mowing of the vegetation and maintenance of the waterway.

Broad-bottom trapezoidal channels require less excavation depth than parabolic. But sediment may be deposited in trapezoidal channels during low flow periods, and cause meandering of higher flows and possible washout of the waterway. Side slopes should be 4 horizontal:1 vertical or flatter, with 10:1 preferable to permit machinery crossing and mowing of the vegetation (Figure 4.2). Most waterways constructed with a trapezoidal section tend to revert to a parabolic cross-section in time.

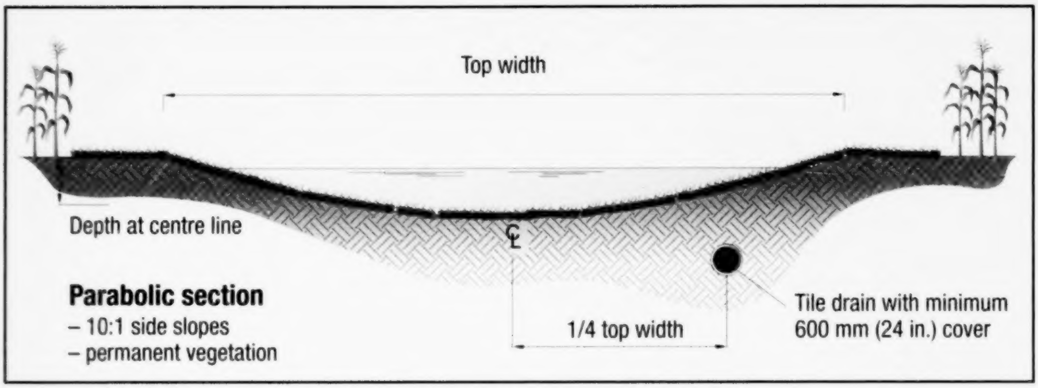


Figure 4.1. Typical Cross-section of Parabolic Grassed Waterway

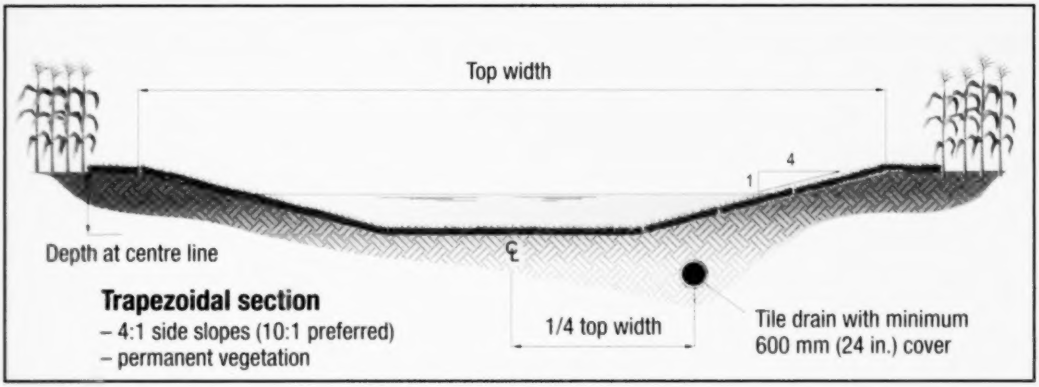


Figure 4.2. Typical Cross-section of Trapezoidal Grassed Waterway

Waterway Location

The waterway is located in the field area where concentrated flows of surplus water are crossing and causing erosion of the soil. This location is generally in a natural draw or swale across the farm. Visible effects of erosion are evident after the heavy spring runoff.

Advantages of a Grassed Waterway

- carries large flows of water
- allows farm machinery to cross
- requires low maintenance once established
- provides option to harvest waterway vegetation as forage
- improves appearance of swale areas

Disadvantages of a Grassed Waterway

- presents difficulty for farm equipment to work around waterway
- provides inadequate depth for tile drainage outlet
- makes it difficult to establish vegetation
- removes land from production if forage crops aren't grown

Waterway Grade

According to design principles, the grade of a grassed waterway may range from less than 1% up to 10%. In practice, however, a grade range of 1% to 5% is most satisfactory. Steep grades (>5%) require wider waterways to maintain a safe flow velocity, and remove more land from potential cropping. Better construction workmanship is also necessary with steeper graded channels to provide a uniform cross-section in the waterway to successfully spread the water out. There is less risk of waterway washout with grades maintained in the 1% to 5% range.

If the natural waterway grade is less than 1%, cut more depth to provide the 1% grade. A very shallow grade can result in ponding of the water, siltation and meandering of the flow, unless high quality workmanship is used to cut waterway grades. The ponding of water on the waterway produces wet spongy areas that are very difficult to cross with farm equipment for most of the year.

On the other hand, when the natural channel grade is more than 5%, install drop structures at critical locations throughout the waterway to reduce the grade to 5%. Gabion basket drop structures and rock chute spillways are commonly used to reduce the grade. For excessively steep grades, consider lining the waterway centre with an erosion-resistant material. Properly designed rock chutes, gabion mattress channels or interlocking blocks can effectively handle the water.

Waterway Design

The design of a waterway determines the channel dimensions that will carry the estimated flow without damage to the channel or its lining. Adhere to safe velocities for the vegetative lining and the waterway to ensure a stable channel.

Waterway Size

Waterways are sized to carry the concentrated surface flow of water contributed by the drainage basin above. Use topographic maps to identify and mark the boundaries of the watershed that contribute water to the waterway. Also mark the approximate waterway location on the topographic map.

Calculate the volume of water contributed by the watershed based on the peak flow method described in Section 2.3. The 10-year return period storm is a sound basis for grassed waterway design.

Waterways are often designed where the grade changes significantly throughout the channel or where there's a large difference in acreage contributing to the waterway at various points along it. In these cases, consider designing the waterway in reaches or sections. A reach is a portion of the waterway having a near uniform slope and drainage area. Design a new reach if a diversion or other tributary enters the waterway adding a significant flow of water. Install a transition between reaches where significant differences in velocity or capacity occur. The resulting waterway will change in depth and width at these points with the transitions installed to connect the sections.

Design Data

After calculating the design flow for the waterway, the following information is required for designing a waterway.

Grade of the Proposed Waterway

- Grades for the proposed waterway or reaches of the waterway are obtained in the field by use of a differential leveling survey.
- If a uniform natural channel slope is found, an average grade for the entire waterway can be used in design.
- Sudden changes in the channel slope will produce sections with different grades and designs required for each section.
- Steep grades produce increasing turbulence and more localized erosion.
- When natural steeper grades are encountered, the width of the waterway is increased to spread the water out and reduce its eroding capability.

Erodibility of the Soil Throughout the Proposed Waterway Area

- Use soil maps to identify the soil class throughout the proposed waterway area and visit the site to confirm the soil type.
- Select the permissible velocity for the waterway based on the soil horizon into which the channel is excavated.
- Table 4.1 gives an indication of the general susceptibility of soil texture to erosion.
- As the soil erodibility potential increases, a lower permissible velocity has to be designed for in order to lessen the possibility of washout.

The Type, Condition and Density of Vegetation for the Proposed Waterway

- Short grass offers less resistance to flow than rank growth.
- Uniformity of cover is very important, as the stability of the most sparsely vegetated area controls the stability of the channel during the period of the establishment of vegetation.
- The bare soil waterway base is very susceptible to erosion. A mulch cover may be considered during this stage to retard the flow and reduce washout problems.
- Permissible velocity for bunch grasses is lower than for sod-forming grasses. Bunch grasses produce non-uniform flows with high localized erosion.

Table 4.1. General Susceptibility of Soil Textures to Erosion

Surface Soil Texture	Relative Susceptibility to Water Erosion*
Very fine sand	very high (very erodible)
Loamy very fine sand Silt loam Very fine sandy loam Silty clay loam	high (erodible)
Clay loam Loam Silty clay Clay Sandy clay loam Fine sand Heavy clay	medium (moderately erodible)
Sandy loam Loamy fine sand Fine sand Coarse sandy loam	low (slightly erodible)
Loamy sand Sand	very low (erosion resistant)

*Based on calculated soil erodibilities for 1,600 surface samples taken in southern Ontario, and on inherent soil erodibility classes included in the Ministry of Transportation Manual

The permissible or safe water velocity for the waterway is dependent on the factors outlined above – waterway grade, soil erodibility and vegetative cover. Table 4.2 gives permissible velocity ranges recommended for several common vegetative linings, as well as for a bare earth channel.

Table 4.2. Permissible Velocities* for Waterway Linings

Waterway Lining	Highly and Moderately Erodible Soils	Slightly Erodible and Erosion-Resistant Soils
Tall fescue Creeping red fescue	1.52 m/s (5 ft/s)	2.13 m/s (7 ft/s)
Grass-legume mixture	1.22 m/s (4 ft/s)	1.52 m/s (5 ft/s)
Alfalfa Native clover, i.e. white dutch clover Annuals, i.e. small grains	0.76 m/s (2.5 ft/s)	1.07 m/s (3.5 ft/s)
Bare earth	0.45 m/s (1.5 ft/s)	0.76 m/sec (2.5 ft/s)

*Permissible velocities are for waterway slopes of 1% to 5%

Consider the following guidelines when selecting a permissible velocity for the waterway:

- Use a maximum velocity of 1 m/s (3 ft/s) where, because of shade, soils or climate, only sparse cover can be established or maintained.
- Use a velocity of 1-1.22 m/s (3-4 ft/s) under normal conditions where vegetation is established by seeding.
- Use a velocity of 1.22-1.52 m/s (4-5 ft/s) only in areas where a dense, vigorous sod is obtained quickly.
- Use a velocity of 1.52-1.83 m/s (5-6 ft/s) on well established sod of good quality.

From field experience, design seeded farm waterways using a maximum permissible velocity of 1.22 m/s (4 ft/s) regardless of the vegetative cover. The critical period for the waterway is the first two to three months when the vegetation is establishing. Unless a mulch is applied during this period, the permissible velocity is only in the range of 0.45-0.76 m/s (1.5-2.5 ft/s) (Table 4.2). As a result, design a lower permissible velocity to provide some protection for the waterway during the establishment period. Farmers have different management abilities in terms of establishing the waterway and maintaining it, e.g. fertilization and clipping of waterway vegetation. Since there is no control over the maintenance of the waterway, select a lower permissible velocity to provide a factor of safety for the contractor and designer.

If sod or rock riprap is placed in the waterway, an immediate resistance to flow is achieved and a higher permissible velocity may be designed for.

Vegetative Retardance

Vegetation is a kind of surface roughness that retards the flow of water and reduces the capacity of the channel. The degree of retardance varies with the type of grasses used and height of the stand. Newly mowed grass, less than 150 mm (6 in.) in height, offers less resistance than tall rank growth. Vegetation is grouped into five retardance categories designated A through E. Table 4.3 gives the portion of this classification of vegetation by degree of retardance commonly used for designs of grassed waterways.

Table 4.3. Classification of Vegetative Cover According to Retardance

Retardance	Vegetative Cover	Vegetative Condition
B	Tall fescue (e.g. Kentucky-31) Grass-legume mixture	Uncut 300 mm (12 in.) Uncut 300 mm (12 in.)
C	Tall fescue Grass-legume mixture	Mowed 150 mm (6 in.) Uncut 150-200 mm (6-8 in.)
D	Creeping red fescue Grass-legume mixture	Headed 100-130 mm (4-5 in.) Uncut 100-130 mm (4-5 in.)

The retardance D is recommended when designing the waterway for safe velocity when the vegetation is short. To maintain safe velocities with the short vegetation, design a waterway that's wider and shallower to reduce the eroding potential of the water. After designing the waterway for safe velocity, check it for capacity to accommodate the peak flow under conditions where the vegetation gives the highest retardance. Retardance B is the most conservative selection for this vegetative condition and is used for designing waterway capacity in this manual. When both the safe velocity and capacity requirements are met, a satisfactory waterway size has been selected.

A trial and error process is normally used to calculate the waterway dimensions using Manning's equation. Due to the complexity of solving problems using Manning's equation, a set of tables (Tables 4.4-M to 4.9-M (4.4-I to 4.9-I)) are included to simplify the selection of the waterway dimensions.

Design Procedure

1. Obtain the design flow (from procedure in Section 2.3) for the waterway.
2. Determine the grade(s) for the proposed waterway from levels taken in the field.
3. Determine the permissible velocity of flow for the channel from Table 4.2 – maximum 1.22 m/s (4 ft/s).
4. Using Tables 4.4-M to 4.9-M (4.4-I to 4.9-I), retardance D and B, select the waterway dimensions to carry the design flow. Both V_1 and V_2 from the tables must be equal to or less than the permissible velocity selected for the waterway.
5. The dimensions for waterways provided by Tables 4.4-M to 4.9-M (4.4-I to 4.9-I) are the minimums required to carry the actual flow. Add a freeboard of 100-150 mm (0.3-0.5 ft) to the design depth for space occupied by vegetation and sedimentation.
6. Check waterway dimensions for traversing with farm equipment.

Other Design Considerations

- If the slope is variable along the waterway, or if there is a large difference in acreage contributing to the waterway at various points along the channel, design the waterway in sections using the above procedure.
- If the waterway width is reduced or enlarged, use a transition where both the width and depth are uniformly changed.
- Ensure the design velocity is within the limits of the permissible velocity and not more than 1.22 m/s (4 ft/s).
- Consider farm equipment crossing when selecting waterway dimensions. Large combines, for example, may need a significant increase in waterway width and reduction in depth to allow for easy crossing.

Notes to Tables 4.4-M to 4.9-M (4.4-I to 4.9-I)

- All tables are prepared using velocity V_1 for retardance D and velocity V_2 for retardance B.
- V_1 represents the maximum permissible velocity when vegetative lining is short (retardance D). V_2 represents the velocity when vegetation is tall (retardance B). This complies with requirements for safe velocity when vegetation is short and capacity when vegetation is tall.
- Tables are prepared for waterway grades from 0.5% to 5%.
- If a waterway width has to be increased for farm machinery crossing, use the tables and either 1) maintain design flow while reducing V_1 or move horizontally to the left on the table, or 2) overdesign by increasing flow, Q, while maintaining V_1 or move vertically down the table.

Table 4.4-M. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B
Grade 0.5% **for Parabolic Waterway**

V_1, V_2 = metres per second, T, D = metres

Q	$V_1 = 0.76$			$V_1 = 0.91$			$V_1 = 1.07$			$V_1 = 1.22$		
m^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
0.42												
0.57												
0.71	**3.4**	**0.80**	**0.43**									
0.85	3.7	0.75	0.43	3.0	0.88	0.49						
0.99	**4.4**	**0.75**	**0.46**	**3.4**	**0.85**	**0.52**						
1.13	4.9	0.73	0.46	3.7	0.82	0.55						
1.24	**5.5**	**0.73**	**0.46**	**4.3**	**0.82**	**0.55**						
1.42	6.1	0.73	0.46	4.6	0.80	0.58	3.4	0.98	2.1			
1.56	**6.7**	**0.73**	**0.49**	**5.2**	**0.80**	**0.58**	**3.7**	**0.94**	**2.2**			
1.70	7.3	0.73	0.49	5.5	0.80	0.58	4.0	0.94	2.2			
1.84	**7.9**	**0.73**	**0.49**	**6.1**	**0.80**	**0.58**	**4.3**	**0.91**	**2.3**			
1.98	8.5	0.73	0.49	6.4	0.80	0.58	4.6	0.91	2.3			
2.12	**9.1**	**0.73**	**0.49**	**6.7**	**0.80**	**0.58**	**4.9**	**0.91**	**2.3**	**4.0**	**1.07**	**0.76**
2.26	9.8	0.73	0.49	7.3	0.80	0.58	5.2	0.91	2.4	4.0	1.04	0.79
2.55	**11.0**	**0.73**	**0.49**	**8.2**	**0.80**	**0.61**	**5.8**	**0.91**	**2.4**	**4.6**	**1.04**	**0.79**
2.83	12.2	0.70	0.49	9.1	0.80	0.61	6.4	0.88	2.4	5.2	1.01	0.82
3.11	**13.4**	**0.70**	**0.49**	**10.1**	**0.80**	**0.61**	**7.0**	**0.88**	**2.4**	**5.5**	**1.01**	**0.85**
3.40	14.6	0.70	0.49	11.0	0.80	0.61	7.6	0.88	2.5	6.1	0.98	0.85
3.68	**15.8**	**0.70**	**0.49**	**11.9**	**0.80**	**0.61**	**8.2**	**0.88**	**2.5**	**6.4**	**0.98**	**0.85**
3.96	16.8	0.70	0.49	12.5	0.80	0.61	8.8	0.88	2.5	7.0	0.98	0.85
4.25	**18.3**	**0.70**	**0.49**	**13.4**	**0.80**	**0.61**	**9.4**	**0.88**	**2.5**	**7.3**	**0.98**	**0.88**

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.4-I. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 0.5% for Parabolic Waterway

V_1, V_2 = feet per second, T, D = feet

Q	V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
ft³/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15												
20												
25	11	2.6	1.4									
30	12	2.5	1.4	10	2.9	1.6						
35	14	2.5	1.5	11	2.8	1.7						
40	16	2.4	1.5	12	2.7	1.8						
45	18	2.4	1.5	14	2.7	1.8						
50	20	2.4	1.5	15	2.6	1.9	11	3.2	2.1			
55	22	2.4	1.6	17	2.6	1.9	12	3.1	2.2			
60	24	2.4	1.6	18	2.6	1.9	13	3.1	2.2			
65	26	2.4	1.6	20	2.6	1.9	14	3.0	2.3			
70	28	2.4	1.6	21	2.6	1.9	15	3.0	2.3			
75	30	2.4	1.6	22	2.6	1.9	16	3.0	2.3	13	3.5	2.5
80	32	2.4	1.6	24	2.6	1.9	17	3.0	2.4	13	3.4	2.6
90	36	2.4	1.6	27	2.6	2.0	19	3.0	2.4	15	3.4	2.6
100	40	2.3	1.6	30	2.6	2.0	21	2.9	2.4	17	3.3	2.7
110	44	2.3	1.6	33	2.6	2.0	23	2.9	2.4	18	3.3	2.8
120	48	2.3	1.6	36	2.6	2.0	25	2.9	2.5	20	3.2	2.8
130	52	2.3	1.6	39	2.6	2.0	27	2.9	2.5	21	3.2	2.8
140	55	2.3	1.6	41	2.6	2.0	29	2.9	2.5	23	3.2	2.8
150	60	2.3	1.6	44	2.6	2.0	31	2.9	2.5	24	3.2	2.9

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.5-M. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 1.0% for Parabolic Waterway

V_1, V_2 = metres per second, T, D = metres

Q	V_1 = 0.76			V_1 = 0.91			V_1 = 1.07			V_1 = 1.22		
m^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
0.42	3.0	0.55	0.37									
0.57	4.0	0.52	0.40	2.7	0.61	0.52						
0.71	4.9	0.52	0.40	3.4	0.61	0.52	2.7	0.67	0.58			
0.85	5.8	0.52	0.43	4.0	0.58	0.55	3.4	0.64	0.61			
0.99	7.0	0.52	0.43	4.6	0.58	0.55	3.7	0.64	0.64	2.7	0.73	0.73
1.13	7.9	0.52	0.43	5.2	0.58	0.55	4.3	0.61	0.64	3.0	0.70	0.76
1.24	8.8	0.52	0.43	5.8	0.58	0.55	4.6	0.61	0.64	3.7	0.70	0.76
1.42	9.8	0.52	0.43	6.4	0.58	0.58	5.2	0.61	0.67	4.0	0.70	0.76
1.56	10.7	0.52	0.43	7.0	0.58	0.58	5.8	0.61	0.67	4.3	0.70	0.79
1.70	11.6	0.52	0.43	7.6	0.58	0.58	6.1	0.61	0.67	4.6	0.67	0.79
1.84	12.5	0.52	0.43	8.5	0.58	0.58	6.7	0.61	0.67	5.2	0.67	0.79
1.98	13.7	0.52	0.43	9.1	0.58	0.58	7.3	0.61	0.67	5.5	0.67	0.79
2.12	14.6	0.52	0.43	9.8	0.58	0.58	7.6	0.61	0.67	5.8	0.67	0.79
2.26	15.5	0.52	0.43	10.4	0.58	0.58	8.2	0.61	0.67	6.1	0.67	0.79
2.55	17.4	0.52	0.43	11.6	0.58	0.58	9.1	0.61	0.67	7.0	0.67	0.82
2.83	19.2	0.52	0.43	12.8	0.58	0.58	10.4	0.61	0.67	7.6	0.67	0.82
3.11	21.3	0.52	0.43	14.0	0.58	0.58	11.3	0.61	0.70	8.5	0.67	0.82
3.40	23.2	0.52	0.43	15.2	0.58	0.58	12.2	0.61	0.70	9.1	0.67	0.82
3.68	25.0	0.52	0.43	16.5	0.58	0.58	13.1	0.61	0.70	10.1	0.67	0.82
3.96	26.8	0.52	0.43	18.0	0.58	0.58	14.3	0.61	0.70	10.7	0.67	0.82
4.25	29.0	0.52	0.43	19.2	0.58	0.58	15.2	0.61	0.70	11.6	0.67	0.82

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.5-I. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 1.0% for Parabolic Waterway

V_1, V_2 = feet per second, T, D = feet

Q	$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$		
ft³/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	10	1.8	1.2									
20	13	1.7	1.3	9	2.0	1.7						
25	16	1.7	1.3	11	2.0	1.7	9	2.2	1.9			
30	19	1.7	1.4	13	1.9	1.8	11	2.1	2.0			
35	23	1.7	1.4	15	1.9	1.8	12	2.1	2.1	9	2.4	2.4
40	26	1.7	1.4	17	1.9	1.8	14	2.0	2.1	10	2.3	2.5
45	29	1.7	1.4	19	1.9	1.8	15	2.0	2.1	12	2.3	2.5
50	32	1.7	1.4	21	1.9	1.9	17	2.0	2.2	13	2.3	2.5
55	35	1.7	1.4	23	1.9	1.9	19	2.0	2.2	14	2.3	2.6
60	38	1.7	1.4	25	1.9	1.9	20	2.0	2.2	15	2.2	2.6
65	41	1.7	1.4	28	1.9	1.9	22	2.0	2.2	17	2.2	2.6
70	45	1.7	1.4	30	1.9	1.9	24	2.0	2.2	18	2.2	2.6
75	48	1.7	1.4	32	1.9	1.9	25	2.0	2.2	19	2.2	2.6
80	51	1.7	1.4	34	1.9	1.9	27	2.0	2.2	20	2.2	2.6
90	57	1.7	1.4	38	1.9	1.9	30	2.0	2.2	23	2.2	2.7
100	63	1.7	1.4	42	1.9	1.9	34	2.0	2.2	25	2.2	2.7
110	70	1.7	1.4	46	1.9	1.9	37	2.0	2.3	28	2.2	2.7
120	76	1.7	1.4	50	1.9	1.9	40	2.0	2.3	30	2.2	2.7
130	82	1.7	1.4	54	1.9	1.9	43	2.0	2.3	33	2.2	2.7
140	88	1.7	1.4	59	1.9	1.9	47	2.0	2.3	35	2.2	2.7
150	95	1.7	1.4	63	1.9	1.9	50	2.0	2.3	38	2.2	2.7

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.6-M. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 2.0% for Parabolic Waterway

V_1, V_2 = metres per second, T, D = metres

Q	V_1= 0.76			V_1= 0.91			V_1= 1.07			V_1= 1.22		
m^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
0.42	4.6	0.40	0.36	3.4	0.43	0.43	2.4	0.49	0.55			
0.57	6.1	0.40	0.36	4.6	0.43	0.46	3.0	0.46	0.58	2.4	0.52	0.70
0.71	7.6	0.40	0.36	5.5	0.43	0.46	4.0	0.46	0.61	2.7	0.52	0.73
0.85	9.1	0.40	0.36	6.7	0.43	0.46	4.6	0.46	0.61	3.4	0.49	0.76
0.99	10.7	0.40	0.36	7.6	0.43	0.46	5.5	0.46	0.61	4.0	0.49	0.76
1.13	12.2	0.40	0.36	8.8	0.43	0.46	6.1	0.46	0.61	4.6	0.49	0.76
1.24	13.7	0.40	0.36	9.8	0.43	0.46	7.0	0.46	0.61	4.9	0.49	0.76
1.42	15.2	0.40	0.36	11.0	0.43	0.49	7.6	0.46	0.61	5.5	0.49	0.79
1.56	16.4	0.40	0.36	11.9	0.40	0.49	8.5	0.46	0.61	6.1	0.49	0.79
1.70	18.0	0.40	0.36	13.1	0.40	0.49	9.1	0.46	0.61	6.7	0.49	0.79
1.84	19.5	0.40	0.36	14.0	0.40	0.49	10.0	0.46	0.61	7.0	0.49	0.79
1.98	20.0	0.40	0.36	15.2	0.40	0.49	10.7	0.46	0.64	7.6	0.49	0.79
2.12	22.2	0.40	0.36	16.2	0.40	0.49	11.3	0.46	0.64	8.2	0.49	0.79
2.26	23.8	0.40	0.36	17.4	0.40	0.49	12.2	0.46	0.64	8.8	0.49	0.79
2.55	26.8	0.40	0.36	19.5	0.40	0.49	13.7	0.46	0.64	9.8	0.49	0.79
2.83	29.6	0.40	0.36	21.6	0.40	0.49	15.2	0.46	0.64	11.0	0.49	0.79
3.11	32.6	0.40	0.36	23.5	0.40	0.49	16.8	0.46	0.64	11.9	0.49	0.79
3.40	35.7	0.40	0.36	25.6	0.40	0.49	18.3	0.46	0.64	13.1	0.49	0.79
3.68	38.4	0.40	0.36	27.7	0.40	0.49	19.5	0.46	0.64	14.0	0.49	0.79
3.96	41.1	0.40	0.36	29.9	0.40	0.49	20.0	0.46	0.64	15.2	0.49	0.79
4.25	44.2	0.40	0.36	32.0	0.40	0.49	22.6	0.46	0.64	16.2	0.49	0.82

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.6-I. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 2.0% for Parabolic Waterway

V_1, V_2 = feet per second, T, D = feet

Q	$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$		
ft^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	15	1.3	1.2	11	1.4	1.4	8	1.6	1.8			
20	20	1.3	1.2	15	1.4	1.5	10	1.5	1.9	8	1.7	2.3
25	25	1.3	1.2	18	1.4	1.5	13	1.5	2.0	9	1.7	2.4
30	30	1.3	1.2	22	1.4	1.5	15	1.5	2.0	11	1.6	2.5
35	35	1.3	1.2	25	1.4	1.5	18	1.5	2.0	13	1.6	2.5
40	40	1.3	1.2	29	1.4	1.5	20	1.5	2.0	15	1.6	2.5
45	45	1.3	1.2	32	1.4	1.5	23	1.5	2.0	16	1.6	2.5
50	50	1.3	1.2	36	1.4	1.6	25	1.5	2.0	18	1.6	2.6
55	54	1.3	1.2	39	1.3	1.6	28	1.5	2.0	20	1.6	2.6
60	59	1.3	1.2	43	1.3	1.6	30	1.5	2.0	22	1.6	2.6
65	64	1.3	1.2	46	1.3	1.6	33	1.5	2.0	23	1.6	2.6
70	69	1.3	1.2	50	1.3	1.6	35	1.5	2.1	25	1.6	2.6
75	73	1.3	1.2	53	1.3	1.6	37	1.5	2.1	27	1.6	2.6
80	78	1.3	1.2	57	1.3	1.6	40	1.5	2.1	29	1.6	2.6
90	88	1.3	1.2	64	1.3	1.6	45	1.5	2.1	32	1.6	2.6
100	97	1.3	1.2	71	1.3	1.6	50	1.5	2.1	36	1.6	2.6
110	107	1.3	1.2	77	1.3	1.6	55	1.5	2.1	39	1.6	2.6
120	117	1.3	1.2	84	1.3	1.6	60	1.5	2.1	43	1.6	2.6
130	126	1.3	1.2	91	1.3	1.6	64	1.5	2.1	46	1.6	2.6
140	135	1.3	1.2	98	1.3	1.6	69	1.5	2.1	50	1.6	2.6
150	145	1.3	1.2	105	1.3	1.6	74	1.5	2.1	53	1.6	2.7

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.7-M. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 3.0% for Parabolic Waterway

V_1, V_2 = metres per second, T, D = metres

Q	V_1 = 0.76			V_1 = 0.91			V_1 = 1.07			V_1 = 1.22		
m^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
0.42	5.8	0.30	0.36	4.0	0.36	0.46	3.0	0.37	0.55	2.4	0.43	0.64
0.57	7.9	0.30	0.36	5.5	0.36	0.46	4.3	0.37	0.55	3.0	0.40	0.67
0.71	9.7	0.30	0.36	6.7	0.36	0.46	5.2	0.37	0.55	4.0	0.40	0.67
0.85	11.6	0.30	0.36	8.2	0.36	0.46	6.1	0.37	0.55	4.6	0.40	0.70
0.99	13.4	0.30	0.36	9.4	0.36	0.46	7.3	0.37	0.55	5.2	0.40	0.70
1.13	15.5	0.30	0.36	10.7	0.36	0.46	8.2	0.37	0.55	6.1	0.40	0.70
1.24	17.4	0.30	0.36	12.2	0.36	0.46	9.1	0.37	0.55	6.7	0.40	0.70
1.42	19.2	0.30	0.36	13.4	0.36	0.46	10.4	0.37	0.55	7.6	0.40	0.70
1.56	21.0	0.30	0.36	14.6	0.36	0.46	11.3	0.37	0.55	8.2	0.40	0.70
1.70	22.9	0.30	0.36	16.2	0.36	0.46	12.2	0.37	0.58	8.8	0.40	0.70
1.84	24.7	0.30	0.36	17.4	0.36	0.46	13.1	0.37	0.58	9.8	0.40	0.73
1.98	26.5	0.30	0.36	18.6	0.36	0.46	14.3	0.37	0.58	10.4	0.40	0.73
2.12	28.7	0.30	0.36	19.8	0.36	0.46	15.2	0.37	0.58	11.3	0.40	0.73
2.26	30.5	0.30	0.36	21.3	0.36	0.46	16.2	0.37	0.58	11.9	0.40	0.73
2.55	34.1	0.30	0.36	23.7	0.36	0.46	18.3	0.37	0.58	13.4	0.40	0.73
2.83	37.8	0.30	0.36	26.5	0.36	0.46	20.1	0.37	0.58	14.9	0.40	0.73
3.11	41.5	0.30	0.37	29.0	0.36	0.46	22.3	0.37	0.58	16.2	0.40	0.73
3.40	45.1	0.30	0.37	31.7	0.36	0.46	24.4	0.37	0.58	17.7	0.40	0.73
3.68	48.9	0.30	0.37	34.1	0.36	0.46	26.2	0.37	0.58	19.2	0.40	0.73
3.96	52.4	0.30	0.37	36.9	0.36	0.46	28.0	0.37	0.58	20.7	0.40	0.73
4.25	56.1	0.30	0.37	39.3	0.36	0.46	30.2	0.37	0.58	21.9	0.40	0.73

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.7-I. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 3.0% for Parabolic Waterway

V_1, V_2 = feet per second, T, D = feet

Q	$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$		
ft^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	19	1.0	1.1	13	1.1	1.5	10	1.2	1.8	8	1.4	2.1
20	26	1.0	1.1	18	1.1	1.5	14	1.2	1.8	10	1.3	2.2
25	32	1.0	1.1	22	1.1	1.5	17	1.2	1.8	13	1.3	2.2
30	38	1.0	1.1	27	1.1	1.5	20	1.2	1.8	15	1.3	2.3
35	44	1.0	1.1	31	1.1	1.5	24	1.2	1.8	17	1.3	2.3
40	51	1.0	1.1	35	1.1	1.5	27	1.2	1.8	20	1.3	2.3
45	57	1.0	1.1	40	1.1	1.5	30	1.2	1.8	22	1.3	2.3
50	63	1.0	1.1	44	1.1	1.5	34	1.2	1.8	25	1.3	2.3
55	69	1.0	1.1	48	1.1	1.5	37	1.2	1.8	27	1.3	2.3
60	75	1.0	1.1	53	1.1	1.5	40	1.2	1.9	29	1.3	2.3
65	81	1.0	1.1	57	1.1	1.5	43	1.2	1.9	32	1.3	2.4
70	87	1.0	1.1	61	1.1	1.5	47	1.2	1.9	34	1.3	2.4
75	94	1.0	1.1	65	1.1	1.5	50	1.2	1.9	37	1.3	2.4
80	100	1.0	1.1	70	1.1	1.5	53	1.2	1.9	39	1.3	2.4
90	112	1.0	1.1	78	1.1	1.5	60	1.2	1.9	44	1.3	2.4
100	124	1.0	1.1	87	1.1	1.5	66	1.2	1.9	49	1.3	2.4
110	136	1.0	1.2	95	1.1	1.5	73	1.2	1.9	53	1.3	2.4
120	148	1.0	1.2	104	1.1	1.5	80	1.2	1.9	58	1.3	2.4
130	160	1.0	1.2	112	1.1	1.5	86	1.2	1.9	63	1.3	2.4
140	172	1.0	1.2	121	1.1	1.5	92	1.2	1.9	68	1.3	2.4
150	184	1.0	1.2	129	1.1	1.5	99	1.2	1.9	72	1.3	2.4

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.8-M. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 4.0% for Parabolic Waterway

V_1, V_2 = metres per second, T, D = metres

Q	$V_1 = 0.76$			$V_1 = 0.91$			$V_1 = 1.07$			$V_1 = 1.22$		
m^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
0.42	7.3	0.27	0.30	4.9	0.30	0.43	3.6	0.34	0.52	2.7	0.37	0.64
0.57	9.4	0.27	0.30	6.7	0.30	0.43	4.9	0.34	0.52	3.6	0.37	0.64
0.71	11.9	0.27	0.30	8.2	0.30	0.43	6.1	0.34	0.52	4.6	0.37	0.64
0.85	14.3	0.27	0.30	9.8	0.30	0.43	7.3	0.34	0.52	5.5	0.34	0.64
0.99	16.8	0.27	0.30	11.6	0.30	0.43	8.5	0.34	0.52	6.4	0.34	0.64
1.13	18.9	0.27	0.30	13.1	0.30	0.43	9.8	0.34	0.52	7.3	0.34	0.67
1.24	21.3	0.27	0.30	14.6	0.30	0.43	11.0	0.34	0.52	8.2	0.34	0.67
1.42	23.5	0.27	0.30	16.4	0.30	0.43	12.9	0.34	0.55	9.1	0.34	0.67
1.56	25.9	0.27	0.30	18.0	0.30	0.43	13.4	0.34	0.55	10.0	0.34	0.67
1.70	28.0	0.27	0.30	19.5	0.30	0.43	14.6	0.34	0.55	11.0	0.34	0.67
1.84	30.5	0.27	0.30	21.0	0.30	0.43	15.5	0.34	0.55	11.9	0.34	0.67
1.98	32.6	0.27	0.30	22.6	0.30	0.43	16.8	0.34	0.55	12.8	0.34	0.67
2.12	34.7	0.27	0.34	24.1	0.30	0.43	18.0	0.34	0.55	13.7	0.34	0.67
2.26	37.2	0.27	0.34	25.6	0.30	0.43	19.2	0.34	0.55	14.6	0.34	0.67
2.55	41.8	0.27	0.34	29.0	0.30	0.43	21.3	0.34	0.55	16.4	0.34	0.67
2.83	46.0	0.27	0.34	32.0	0.30	0.43	23.8	0.34	0.55	18.3	0.34	0.67
3.11	50.3	0.27	0.34	35.0	0.30	0.43	26.2	0.34	0.55	19.8	0.34	0.67
3.40	55.2	0.27	0.34	38.4	0.30	0.43	28.3	0.34	0.55	21.6	0.34	0.67
3.68	59.4	0.27	0.34	41.4	0.30	0.43	30.8	0.34	0.55	23.5	0.34	0.67
3.96	64.0	0.27	0.34	44.5	0.30	0.43	33.2	0.34	0.55	25.3	0.34	0.67
4.25	68.3	0.27	0.34	47.5	0.30	0.43	35.4	0.34	0.55	27.1	0.34	0.67

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.8-I Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 4.0% for Parabolic Waterway

V_1, V_2 = feet per second, T, D = feet

Q	$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$		
ft³/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	24	0.9	1.0	16	1.0	1.4	12	1.1	1.7	9	1.2	2.1
20	31	0.9	1.0	22	1.0	1.4	16	1.1	1.7	12	1.2	2.1
25	39	0.9	1.0	27	1.0	1.4	20	1.1	1.7	15	1.2	2.1
30	47	0.9	1.0	32	1.0	1.4	24	1.1	1.7	18	1.1	2.1
35	55	0.9	1.0	38	1.0	1.4	28	1.1	1.7	21	1.1	2.1
40	62	0.9	1.0	43	1.0	1.4	32	1.1	1.7	24	1.1	2.2
45	70	0.9	1.0	48	1.0	1.4	36	1.1	1.7	27	1.1	2.2
50	77	0.9	1.0	54	1.0	1.4	40	1.1	1.8	30	1.1	2.2
55	85	0.9	1.0	59	1.0	1.4	44	1.1	1.8	33	1.1	2.2
60	92	0.9	1.0	64	1.0	1.4	48	1.1	1.8	36	1.1	2.2
65	100	0.9	1.0	69	1.0	1.4	51	1.1	1.8	39	1.1	2.2
70	107	0.9	1.0	74	1.0	1.4	55	1.1	1.8	42	1.1	2.2
75	114	0.9	1.1	79	1.0	1.4	59	1.1	1.8	45	1.1	2.2
80	122	0.9	1.1	84	1.0	1.4	63	1.1	1.8	48	1.1	2.2
90	137	0.9	1.1	95	1.0	1.4	70	1.1	1.8	54	1.1	2.2
100	151	0.9	1.1	105	1.0	1.4	78	1.1	1.8	60	1.1	2.2
110	165	0.9	1.1	115	1.0	1.4	86	1.1	1.8	65	1.1	2.2
120	181	0.9	1.1	126	1.0	1.4	93	1.1	1.8	71	1.1	2.2
130	195	0.9	1.1	136	1.0	1.4	101	1.1	1.8	77	1.1	2.2
140	210	0.9	1.1	146	1.0	1.4	109	1.1	1.8	83	1.1	2.2
150	224	0.9	1.1	156	1.0	1.4	116	1.1	1.8	89	1.1	2.2

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.9-M. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 5.0% for Parabolic Waterway

V_1, V_2 = metres per second, T, D = metres

Q	V_1 = 0.76			V_1 = 0.91			V_1 = 1.07			V_1 = 1.22		
m^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
0.42	7.6	0.27	0.30	5.5	0.27	0.43	4.3	0.30	0.49	3.4	0.30	0.61
0.57	10.4	0.27	0.30	7.3	0.27	0.43	5.8	0.30	0.49	4.3	0.30	0.61
0.71	12.8	0.27	0.30	8.8	0.27	0.43	7.3	0.30	0.49	5.8	0.30	0.64
0.85	15.2	0.27	0.30	10.7	0.27	0.43	8.5	0.30	0.52	6.4	0.30	0.64
0.99	17.7	0.27	0.30	12.5	0.27	0.43	10.1	0.30	0.52	7.3	0.30	0.64
1.13	20.1	0.27	0.30	14.3	0.27	0.43	11.6	0.30	0.52	8.5	0.30	0.64
1.24	22.6	0.27	0.34	15.8	0.27	0.43	12.8	0.30	0.52	9.4	0.30	0.64
1.42	25.0	0.27	0.34	17.7	0.27	0.43	14.3	0.30	0.52	10.7	0.30	0.64
1.56	27.4	0.27	0.34	19.5	0.27	0.43	15.5	0.30	0.52	11.6	0.30	0.64
1.70	29.9	0.27	0.34	21.0	0.27	0.43	17.1	0.30	0.52	12.5	0.30	0.64
1.84	32.3	0.27	0.34	22.9	0.27	0.43	18.6	0.30	0.52	13.7	0.30	0.64
1.98	34.7	0.27	0.34	24.4	0.27	0.43	19.8	0.30	0.52	14.6	0.30	0.64
2.12	37.2	0.27	0.34	26.2	0.27	0.43	21.3	0.30	0.52	15.5	0.30	0.64
2.26	39.6	0.27	0.34	27.7	0.27	0.43	22.6	0.30	0.52	16.8	0.30	0.64
2.55	44.2	0.27	0.34	31.1	0.27	0.43	25.3	0.30	0.52	18.9	0.30	0.64
2.83	49.1	0.27	0.34	34.7	0.27	0.43	28.0	0.30	0.52	20.7	0.30	0.64
3.11	53.9	0.27	0.34	37.8	0.27	0.43	30.8	0.30	0.52	22.9	0.30	0.64
3.40	58.5	0.27	0.34	41.5	0.27	0.43	33.5	0.30	0.52	24.7	0.30	0.64
3.68	63.4	0.27	0.34	44.8	0.27	0.43	36.3	0.30	0.52	26.8	0.30	0.64
3.96	68.0	0.27	0.34	48.2	0.27	0.43	39.0	0.30	0.52	29.0	0.30	0.67
4.25	72.5	0.27	0.34	51.2	0.27	0.43	41.8	0.30	0.52	30.8	0.30	0.67

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Table 4.9-I. Velocity (V_1) for Retardance D – Top Width (T), Depth (D) and Velocity (V_2) for Retardance B Grade 5.0% for Parabolic Waterway

V_1, V_2 = feet per second, T, D = feet

Q	$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$		
ft^3/s	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	25	0.9	1.0	18	0.9	1.4	14	1.0	1.6	11	1.0	2.0
20	34	0.9	1.0	24	0.9	1.4	19	1.0	1.6	14	1.0	2.0
25	42	0.9	1.0	29	0.9	1.4	24	1.0	1.6	18	1.0	2.1
30	50	0.9	1.0	35	0.9	1.4	28	1.0	1.7	21	1.0	2.1
35	58	0.9	1.0	41	0.9	1.4	33	1.0	1.7	24	1.0	2.1
40	66	0.9	1.0	47	0.9	1.4	38	1.0	1.7	28	1.0	2.1
45	74	0.9	1.1	52	0.9	1.4	42	1.0	1.7	31	1.0	2.1
50	82	0.9	1.1	58	0.9	1.4	47	1.0	1.7	35	1.0	2.1
55	90	0.9	1.1	64	0.9	1.4	51	1.0	1.7	38	1.0	2.1
60	98	0.9	1.1	69	0.9	1.4	56	1.0	1.7	41	1.0	2.1
65	106	0.9	1.1	75	0.9	1.4	61	1.0	1.7	45	1.0	2.1
70	114	0.9	1.1	80	0.9	1.4	65	1.0	1.7	48	1.0	2.1
75	122	0.9	1.1	86	0.9	1.4	70	1.0	1.7	51	1.0	2.1
80	130	0.9	1.1	91	0.9	1.4	74	1.0	1.7	55	1.0	2.1
90	145	0.9	1.1	102	0.9	1.4	83	1.0	1.7	62	1.0	2.1
100	161	0.9	1.1	114	0.9	1.4	92	1.0	1.7	68	1.0	2.1
110	177	0.9	1.1	125	0.9	1.4	101	1.0	1.7	75	1.0	2.1
120	192	0.9	1.1	136	0.9	1.4	110	1.0	1.7	81	1.0	2.1
130	208	0.9	1.1	147	0.9	1.4	119	1.0	1.7	88	1.0	2.1
140	223	0.9	1.1	158	0.9	1.4	128	1.0	1.7	95	1.0	2.2
150	238	0.9	1.1	168	0.9	1.4	137	1.0	1.7	101	1.0	2.2

Source: Adapted from Engineering Field Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., July, 1984.

Grassed Waterway Design Information Sheet

1. Watershed area	_____ ha	_____ ac
2. Average grade of watershed	_____ %	
3. Runoff curve number from Tables 2.2 – 2.4	_____	
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)	_____ m^3/s	_____ ft^3/s
5. Waterway length	_____ m	_____ ft
6. Elevation difference throughout waterway length	_____ m	_____ ft
7. Average grade of waterway = $\frac{\text{Elevation difference (6)}}{\text{Waterway length (5)}} \times 100$; $\frac{\_\_\_\ m}{\_\_\_\ m} \times 100$; $\frac{\_\_\_\ ft}{\_\_\_\ ft} \times 100$	_____ %	
8. Soil texture at waterway location		
9. Erodibility of soil at waterway location from Table 4.1		
10. Waterway vegetative cover		
11. Permissible velocity of flow from Table 4.2	_____ m/s	_____ ft/s
12. Waterway dimensions from Table 4.4-M to 4.9-M (4.4-I to 4.9-I)	T = _____ m D = _____ m	_____ ft _____ ft
13. Add 0.1 m (0.3 ft) minimum freeboard to give new waterway dimensions	T = _____ m D = _____ m	_____ ft _____ ft
14. Are waterway dimensions suitable for crossing with farm equipment? e.g. minimum side slope 10 horizontal:1 vertical If NO, repeat steps (12) to (14) and adjust waterway dimensions. If YES, go to step (15).	❑ No ❑ Yes	
15. Final waterway dimensions from step (13)	T = _____ m D = _____ m	_____ ft _____ ft

Grassed Waterway Example Problem #1

Determine the top width and depth dimensions for a parabolic shaped grassed waterway that meets the following requirements:

- design flow = 2.83 m^3/s (100 ft^3/s)
- grade = 3%
- vegetative cover = grass-legume mixture
- soil erodibility = highly erodible

Solution:

Design flow = 2.83 m^3/s (100 ft^3/s)
Grade = 3%
Using Table 4.2, permissible velocity of flow = 1.22 m/s (4 ft/s)

Using Table 4.7-M (4.7-I) for grade of 3%, locate design flow Q = 2.83 m^3/s (100 ft^3/s) in left hand column. Find waterway dimensions where column V_1= 1.22 m/s (V_1 = 4 ft/s) (permissible velocity) intersects row Q = 2.83 m^3/s (Q = 100 ft^3/s).

Top width T = 14.9 m (49 ft)
Depth D = 0.40 m (1.3 ft)
Velocity V_2 = 0.73 m/s (2.4 ft/s)

A parabolic waterway with a top width of 14.9 m (49 ft) and a depth of 0.40 m (1.3 ft) will carry 2.83 m^3/s (100 ft^3/s) at a maximum velocity of 1.22 m/s (4 ft/s) when the vegetative lining is short, and 0.73 m/s (2.4 ft/s) when the vegetative lining is tall. These dimensions comply with requirements for safe velocity when vegetation is short (D retardance) and capacity when vegetation is tall (B retardance).

Add 0.10 m (0.3 ft) freeboard, and the final waterway dimensions are approximately 14.9 m (49 ft) wide x 0.50 m (1.6 ft) deep. These waterway dimensions are suitable for crossing with farm equipment and meet the minimum side slope of 10 horizontal:1 vertical.

Grassed Waterway Design Information Sheet – Example Problem #1

1. Watershed area	N/A	N/A
2. Average grade of watershed	N/A	
3. Runoff curve number from Tables 2.2 – 2.4	N/A	
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)	2.83 m^3/s	100 ft^3/s
5. Waterway length	N/A	
6. Elevation difference throughout waterway length	N/A	
7. Average grade of waterway = $\frac{\text{Elevation difference (6)}}{\text{Waterway length (5)}} \times 100$; $\frac{\_\_\_\ m}{m} \times 100$; $\frac{\_\_\_\ ft}{ft} \times 100$	3%	
8. Soil texture at waterway location	N/A	
9. Erodibility of soil at waterway location from Table 4.1	Highly erodible	
10. Waterway vegetative cover	Grass-legume mixture	
11. Permissible velocity of flow from Table 4.2	1.22 m/s	4 ft/s
12. Waterway dimensions from Table 4.4-M to 4.9-M (4.4-I to 4.9-I)	T = 14.9 m D = 0.40 m	49 ft 1.3 ft
13. Add 0.1 m (0.3 ft) minimum freeboard to give new waterway dimensions	T = 14.9 m D = 0.50 m	49 ft 1.6 ft
14. Are waterway dimensions suitable for crossing with farm equipment? e.g. minimum side slope 10 horizontal:1 vertical If NO, repeat steps (12) to (14) and adjust waterway dimensions. If YES, go to step (15).	☐ No ☑ Yes	
15. Final waterway dimensions from step (13)	T = 14.9 m D = 0.50 m	49 ft 1.6 ft

Grassed Waterway Example Problem #2

Design a parabolic grassed waterway to protect the swale outlined in the watershed sizing example in Section 2.2.4. The watershed is 87.5 ha (216 ac) with an overall slope of 1.58 %. The flow is 1.4 m^3/s (49 ft^3/s). The waterway will be 645 m (2,116 ft) in length with a fall of 11.15 m (36.6 ft), providing a grade of 1.73% on moderately erodible soil. The soils are loam (hydrologic soil group B and good hydrologic condition) with contour row cropping, which results in a runoff curve number of 75. The vegetation to be established on the grassed waterway is a grass-legume mixture.

Solution:

Design flow = 1.4 m^3/s (49 ft^3/s)
Grade = 1.73%
Using Table 4.2, permissible velocity is 1.22 m/s (4.0 ft/s)

Using Table 4.6-M (4.6-I) for grade of 1.73% (use 2%), locate design flow Q = 1.4 m^3/s (49 ft^3/s) (use 1.42 m^3/s) (use 50 ft^3/s) in left hand column. Find waterway dimensions where column V_1 = 1.22 m/s (4.0 ft/s) and intersects row Q = 1.42 m^3/s (50 ft^3/s).

Top width T = 5.5 m (18 ft)
Depth D = 0.49 m (1.6 ft)
Velocity V_2 = 0.79 m/s (2.6 ft/s)

A parabolic waterway with a top width of 5.5 m (18 ft) and depth of 0.49 m (1.6 ft) will carry the design flow of 1.4 m^3/s (49 ft^3/s) at a maximum velocity of 1.22 m/s (4 ft/s) when the vegetative lining is short and 0.79 m/s (2.6 ft/s) when the vegetative lining is tall. These dimensions comply with requirements for safe velocity when vegetation is short (D retardance) and capacity, when vegetation is tall (B retardance).

Add 0.1 m (0.3 ft) freeboard, and the final waterway dimensions are 5.5 m wide x 0.59 m deep (18 ft wide x 1.9 ft deep).

The waterway cross-section does not satisfy requirements for traversing with farm equipment because it is too narrow and deep (ie. does not meet the minimum side slope of 10 horizontal:1 vertical).

To size the waterway, maintain the same flow of Q = 1.4 m^3/s (49 ft^3/s) and using Table 4.6-M (4.6-I), move horizontally to the left to column where the V_1 = 1.07 m/s (3.5 ft/s) reduce waterway depth (D), and increase top width (T). Select new waterway dimensions:

Top width T = 7.6 m (25 ft)
Depth D = 0.46 m (1.5 ft)
Velocity V_2 = 0.61 m/s (2.0 ft/s)

This waterway results in a lower permissible velocity, V_1, for short growth of 1.07 m/s (3.5 ft/s). Adding 0.1 m (0.3 ft) freeboard, final waterway dimensions are:

Top width T = 7.6 m (25 ft)
Depth D = 0.56 m (1.8 ft)

The waterway cross-section does not satisfy requirements for traversing with farm equipment because it is too narrow and deep (i.e. does not meet the minimum side slope of 10 horizontal:1 vertical).

To size the waterway, maintain the same flow of Q = 1.4 m^3/s (49 ft^3/s) and using Table 4.6-M (4.6-I), move horizontally to the left to reduce waterway depth (D), and increase top width (T). Select new waterway dimensions in column where V_1 = 0.91 m/s (3.0 ft/s):

Top width T = 11 m (36 ft)
Depth D = 0.43 m (1.4 ft)
Velocity V_2 = 0.49 m/s (1.6 ft/s)

This waterway results in a lower permissible velocity, V_1, for short growth of 0.91 m/s (3 ft/s). Adding 0.1 m (0.3 ft) freeboard, final waterway dimensions are:

Top width T = 11 m (36 ft)
Depth D = 0.53 m (1.7 ft)

This waterway has dimensions that are acceptable for crossing with farm equipment. The waterway meets the minimum side slope of 10 horizontal:1 vertical.

Grassed Waterway Design Information Sheet – Example Problem #2

1. Watershed area			87.5 ha	216 ac
2. Average grade of watershed				1.58%
3. Runoff curve number from Tables 2.2 – 2.4				75
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)			1.4 m^3/s	49 ft^3/s
5. Waterway length			645 m	2,116 ft
6. Elevation difference throughout waterway length			11.15 m	36.6 ft
7. Average grade of waterway =				1.73%
$\frac{\text{Elevation difference (6)}}{\text{Waterway length (5)}} \times 100$	$\frac{11.15\text{ m}}{645\text{ m}} \times 100$	$\frac{36.6\text{ ft}}{2{,}116\text{ ft}} \times 100$		
8. Soil texture at waterway location				Loam
9. Erodibility of soil at waterway location from Table 4.1				Moderately erodible
10. Waterway vegetative cover				Grass-legume mixture
11. Permissible velocity of flow from Table 4.2			1.22 m/s	4 ft/s
12. Waterway dimensions from Table 4.4-M to 4.9-M (4.4-I to 4.9-I)			T = 11 m D = 0.43 m	36 ft 1.4 ft
13. Add 0.1 m (0.3 ft) minimum freeboard to give new waterway dimensions			T = 11 m D = 0.53 m	36 ft 1.7 ft
14. Are waterway dimensions suitable for crossing with farm equipment? e.g. minimum side slope 10 horizontal:1 vertical If NO, repeat steps (12) to (14) and adjust waterway dimensions. If YES, go to step (15).			☐ No	☑ Yes
15. Final waterway dimensions from step (13)			T = 11 m D = 0.53 m	36 ft 1.7 ft

Drainage of Waterways

To be effective, ensure waterways are not continually wet for long periods of time. Wet conditions inhibit the development and maintenance of a good vegetative cover, and leave soil in a soft and erosive condition. Wet waterways also limit equipment crossing when field work is being done.

Tile Drains

Subsurface drainage is essential to the success of the waterway. Tile lines should parallel the centre of the waterway and be offset from the centre line at least one-fourth the top width of the waterway (Figures 4.1 and 4.2). Tile lines are offset from the centre line to remove them from the area of greatest flow in the waterway, reducing the chance of washout above the lines. In some cases, two lines may be required with one on each side of centre. Provide a minimum of 0.60 m (2 ft) of soil cover over each tile line. Although 100 mm (4 in.) diameter lines are normally installed for subsurface drainage of the grassed waterway, consider larger lines if some surface water is being intercepted by the tile system.

Surface Water Tile Inlets

In some cases, a continuous flow of water may enter the upstream end of the waterway because of a tile drainage system outletting above, or a spring condition. Install a surface water inlet and larger tile line to intercept this water. The surface water inlet can be an open catch basin, a blind inlet or a vertical pipe type inlet installed on the tile line. Design this tile line to carry the anticipated continuous flow of water entering the surface inlet, plus subsurface water under the waterway. Water can also enter the tile at catch basins that intercept channel flow at one or more critical points along the waterway.

Waterway Construction

The procedure and amount of work involved in constructing a grassed waterway depends upon the topographic situation and the equipment available. If a waterway is located in a natural draw with few washout areas, minimal shaping, smoothing and normal seedbed preparation are required. If the waterway is reclaiming an established gully, considerable earthwork is required to fill the gully and establish the waterway cross-section and grade.

Use any equipment capable of moving and smoothing soil to construct a grassed waterway – including large earth-moving equipment such as road graders, land levelers and bulldozers. Farm tillage equipment can shape very small waterways and carry out final smoothing operations for seedbed preparation and seed incorporation.

Construction Procedure

- Remove all trees, stumps and stones from the proposed waterway path.
- Mark the centre line and sides of the proposed waterway with grade stakes to identify the waterway path and channel gradient and side slopes.
- Construct waterway outlet control device (if required) to ensure the correct gradient.
- Rough grade the waterway installing any necessary drop structures. Retain topsoil and spread over constructed waterway for obtaining good vegetative cover.
- Install tile drains beneath waterway at least one quarter of the waterway width away from the centre line with a minimum of 0.6 m (2 ft) soil cover. Install catch basins, blind inlets, etc.
- Prepare a firm seedbed, apply adequate fertilizer and seed the waterway as soon after construction as possible (within 24 hours). Broadcasting with a cyclone seeder is the most effective method of seeding.
- As a temporary measure to help prevent washouts, use a diversion to divert water away from the waterway at the top end. Remove the diversion after vegetation is established. Straw mulch applied after seeding the waterway is another effective protective measure against erosion.

Construction Timing

Construct the waterway when vegetation can be easily established. The preferred construction time is late summer, so seeding is complete by early September and a good vegetative stand establishes before late fall rains. A well established fall vegetative stand also has a good chance of surviving heavy spring flows.

Waterways can also be constructed in early spring with seeding completed as soon after as possible. There is some risk with spring construction of not getting a good vegetative stand established during the hot, dry weather of early summer. When a waterway is constructed in a poorly drained area, the work may have to be completed during the dry months of July and August, with seeding completed in early September.

Start constructing the grassed waterway when there's reasonable assurance that the complete job of shaping and seeding can be finished in as short a time period as possible.

Waterway Seeding

Include a quick-growing annual nurse crop in waterway seeding mixtures (Table 4.10) for temporary control, and hardy perennials for permanent protection. Ensure the seed variety or mixture is adaptable to the site, soil, slope and velocity of expected runoff.

The most appropriate time to construct a waterway to ensure vigorous seed growth is typically April 15 to May 30 and August 1 to September 30. This timing may vary up to two weeks throughout Ontario due to a late spring thaw, an excessively wet spring or autumn, or extended drought conditions.

Table 4.10. Waterway Seeding Mixtures

Application	As a Percent of Mixture	Rate
Permanent Seed		
Creeping red fescue	50	Broadcast at 80 kg/ha (70 lb/ac) Drill at 50 kg/ha (45 lb/ac)
Perennial ryegrass	45	
White clover	5	
Nurse Crop		
Spring or fall grain (rye, wheat, oats, barley, etc.)	100	Broadcast at 80 kg/ha (70 lb/ac) Drill at 50 kg/ha (45 lb/ac)
Fertilizer		
For most soils use: 7-7-7		80 kg/ha (70 lb/ac)
Where nutrients may be limiting consider: 6-24-24 on sandy soil 8-32-16 on clay soil		310 kg/ha (275 lb/ac)

Although tap rooted legumes are not often recommended, alfalfa can be used in an alfalfa-grass mixture and serve as a valuable forage product for the farm.

Apply adequate fertilizer to waterways at the time of seeding and on a regular schedule to maintain a good stand.

Use a hand or all-terrain vehicle mounted cyclone seeder for seeding and fertilizing. This method of broadcasting is preferred over the seed drill which creates rows of vegetation parallel to the flow of water, offering less resistance to erosion of the channel. Tractor tires on seed drills also form trenches in the completed waterway, leading to future erosion.

Use mulching on waterways where it's difficult for vegetation to establish. Mulch protects the surface from erosion, holds seed and fertilizer in place, and maintains soil temperature and moisture. Use dry, unchopped straw at 1,000 kg/ha (900 lb/ac). Evenly distribute the mulch over the waterway – especially the centre portion – by hand, solid manure or blower-type spreader. Anchor the mulch in the soil by going over it lightly with a set of discs.

In areas where immediate protection is necessary and to ensure good grass establishment, consider using prefabricated mulch or erosion control blankets. These products are stapled to the ground and offer excellent conditions for seed germination and growth, while preventing erosion. Most of these products are also biodegradable.

Maintenance of the Grassed Waterway

Grassed waterways need regular attention to keep them in good repair. Follow these maintenance procedures:

- Inspect new waterways for failures immediately after heavy rains the first year, and then annually. Quickly repair and reseed any bare and eroded spots.
- Apply fertilizer to encourage thick vegetation growth.
- Mow the waterway two or three times a year to help thicken the vegetative stand and reduce flow retardance.
- Prevent livestock from accessing the waterway.
- Avoid using grassed waterways as travel lanes for cattle or farm machinery.
- When crossing waterways with farm machinery, raise implements and shut off sprayers to avoid vegetation damage.
- Perform all tillage on adjacent crop land at right angles to the waterway to allow surface water to flow directly into the waterway. Avoid plowing a headland furrow parallel to the waterway – this will create a trench for the water to follow and will eventually form a gully.
- Maintain good tillage and cropping practices on adjacent farm land that promote conservation and minimize soil erosion. These practices help prevent sediment delivery into the waterway which can threaten the integrity of the waterway.

Waterway Outlets

Grassed waterways usually exit into ditches and streams and it's important to design and construct non-erosive outlets at these locations. Construct a chute spillway, drop pipe inlet or grade control structure to carry water from the grassed waterway level to the outlet elevation.

If a waterway exits into a low lying swampy area, the waterway cross-section must be flared out – wider and shallower – as it enters this area.

A grassed waterway must be designed and constructed so that the water exits the channel at an adequate outlet. If water isn't carried to a proper outlet, further erosion and drainage problems will occur on adjacent lands. If a neighbour's land is involved at the outlet, consider the following alternatives:

- Discuss the project with the neighbour and encourage the extension of the waterway across their property; or
- Receive written permission from the neighbour for the outlet location and have the agreement registered.

Both the contractor and farmer are responsible for the waterway outlet installation. If a future problem develops, both parties may be liable for damages caused to the lower landowner.

Waterway Crossing

Grassed waterways are normally designed and constructed to be crossed at any location along their length. However, steep topographic conditions along the side of the waterway, or high water flows during the late fall and early spring periods, may make it difficult to cross at these points.

If a regularly used laneway crosses the grassed waterway, additional protection may be necessary. At this location, install a bed level crossing or consider a soil reinforcement system. These crossings are built on the waterway bed and are constructed of rock riprap, interlocking concrete blocks or a porous pavement system. If a tile has been installed beneath the grassed waterway it may need to be protected with a section of heavy duty plastic or corrugated steel pipe. Section 4.2 provides information on low level crossings.

Waterway Costs

The cost of constructing a grassed waterway will depend on the following factors:

- initial topography of waterway site and the amount of preparation and shaping required
- length of waterway
- associated drop structures, catch basins and tile lines
- type of waterway lining required
- outlet requirement
- soil condition – excess moisture or stones
- other features such as crossings

4.1.2 Open Ditches

An open ditch is normally constructed to assist in the removal of excess water away from an area where it may cause damage. It provides an outlet for surface flow such as during the spring thaw, as well as for underdrainage systems. A well designed open ditch removes water quickly enough from the owner's upstream properties to avoid crop or property damage, and slowly enough to avoid downstream erosion and flooding. These two extremes – as well as environmental concerns – make it impossible to cover the complete design of open ditches for large watersheds in this manual.

Regardless of the size of the open ditch, there are three ingredients necessary to provide prolonged service as a drainage channel – a good initial design, quality construction and regular maintenance. An understanding of ditch design, construction and maintenance will improve the longevity of the ditch and make it more erosion resistant. The following aspects are particularly important in open ditch design:

- berms
- buffer strips
- channel bends
- culvert protection
- ditch side slopes
- ditch bank seeding
- fencing of ditches
- lateral seepage
- lateral surface flows
- maintenance
- steep grades
- timing
- tile outfall protection

Ditch Side Slopes

Different soil types require different side slopes. In general, consider 1.5 horizontal:1 vertical a minimum, with 2:1 preferred. Fine sands and silts may require much flatter side slopes to provide a stable channel. Engineers' drawings usually indicate the side slope by two numbers separated by a colon (e.g. 2:1 or 1.5:1). The first number represents a horizontal distance and the second represents a vertical distance. An important advantage of the flatter slope, other than stability, is that it's easier to get vegetation established on the banks. Table 4.11, the information which is taken from *Design and Construction Guidelines for Work Done Under the Drainage Act, 1980,* gives recommended side slopes for different soil types. Obtain further information from OMAFRA Publication 29, *Drainage Guide for Ontario.*

Table 4.11. Recommended Minimum Side Slopes for Open Ditches

Soil Material	Minimum Slope with Bank Protection*	Minimum Slope without Bank Protection*
Peat, stable organic	1:1	1:1
Heavy clay (>35% clay)	1:1	1.5:1
Clay/silt loam (10% to 35% clay)	1.5:1	2:1
Sandy loamy (<10% clay)	2:1	3:1
Clay of marine origin and/or banded with sand or silt (subject to low stability when saturated)	3:1	4:1
Sandy or silty with high water table and/or lateral seepage	3:1	4:1

*Bank protection refers to one or more of the extra features used to control erosion – vegetation, buffer strips, berms, fencing, etc.

Ditch Bank Seeding

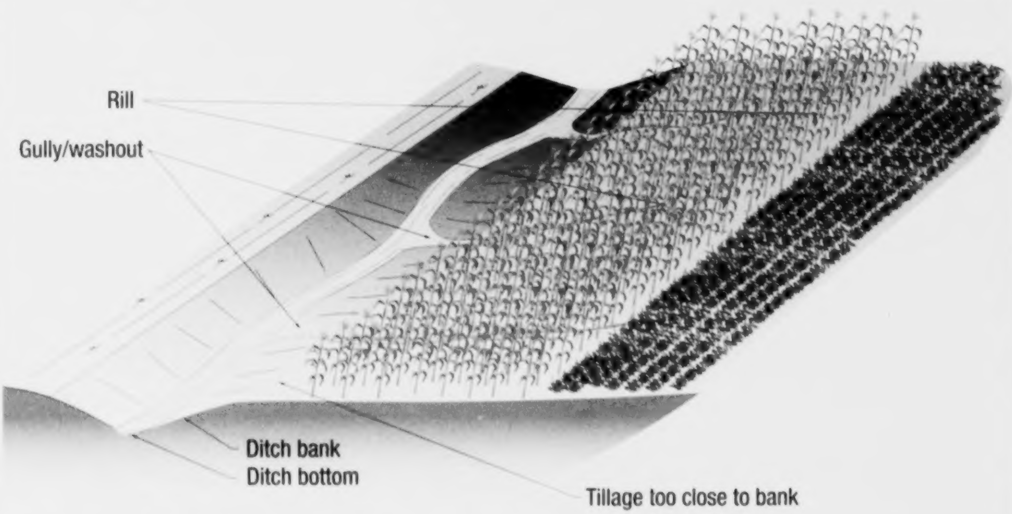
Establishing a vegetative cover on ditch banks is probably the least expensive and most effective method of stabilizing a ditch bank. Determining the seed mixture is the single most serious problem in providing the vegetation required. The seed mixture provided in Section 4.1.1 Grassed Waterway is suitable in most instances. The key to success is daily seeding – the practice of applying the appropriate seed mixture to the raw ditch bank the same day the finished excavation is made. Drainage engineers, drainage superintendents, excavation contractors and ministry staff all attest to this principle as a number of successes are now evident in Ontario.

The seed mixture can vary as long as the final stand has certain properties. If possible, use low-growing seed varieties to avoid restricting flow in the ditch. Refer to Section 3.1 for specific instructions on seed mixtures, application rates and application methods.

Lateral Surface Flows

One of the major causes of ditch bank failures and washouts is concentrated surface flows entering the ditch over the ditch bank. Even small flows – those directed to the ditch by a plow furrow – can cause damage that requires costly repairs. The designer or inspector should locate these areas and provide special means of entering these flows into the ditch. Two common methods of safely entering these flows are using drop inlet catch basins and small chute spillway drop structures.

Figure 4.3 shows typical washout problem that can be corrected with a small chute spillway drop structure or drop inlet catch basin. Figure 4.4 shows some of the details of a good drop inlet catch basin design. Figure 4.5 shows a small rock chute spillway designed to protect a ditch bank.



Typical problem to be solved with small chute spillway drop structure or drop inlet catch basin.
Many washouts and gully problems along ditches are caused when concentrated surface flows enter the ditch where no protection is provided.

Figure 4.3. Ditch Bank Erosion Problem

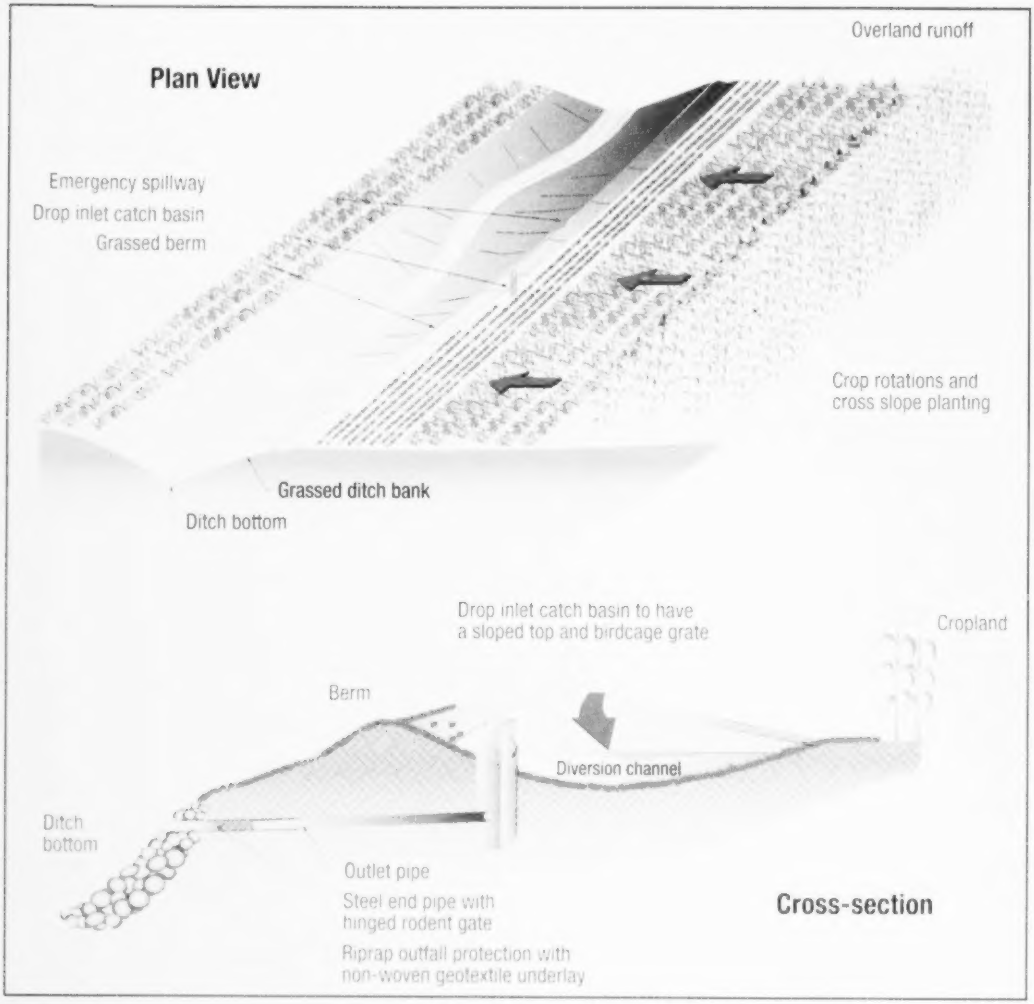


Figure 4.4. Ditch Bank Protection Using a Surface Diversion and Drop Inlet Catch Basin

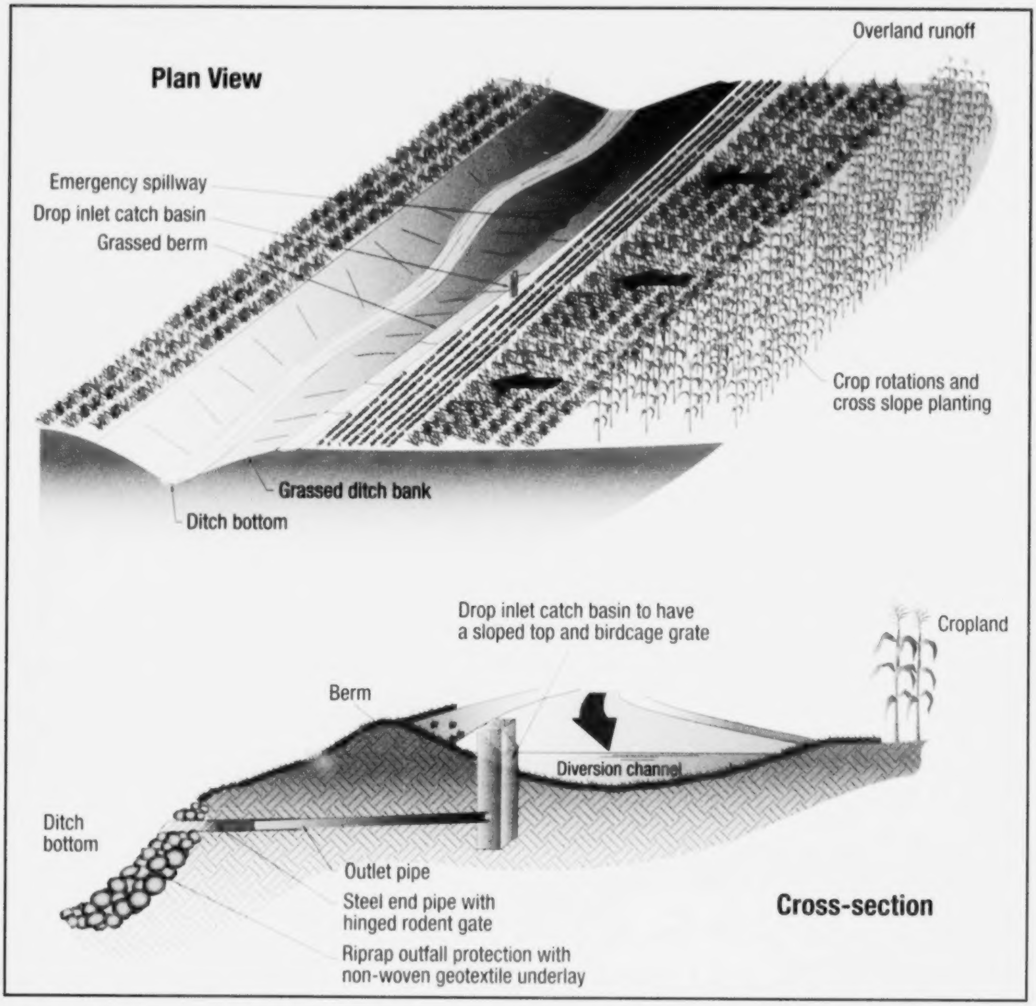


Figure 4.4. Ditch Bank Protection Using a Surface Diversion and Drop Inlet Catch Basin

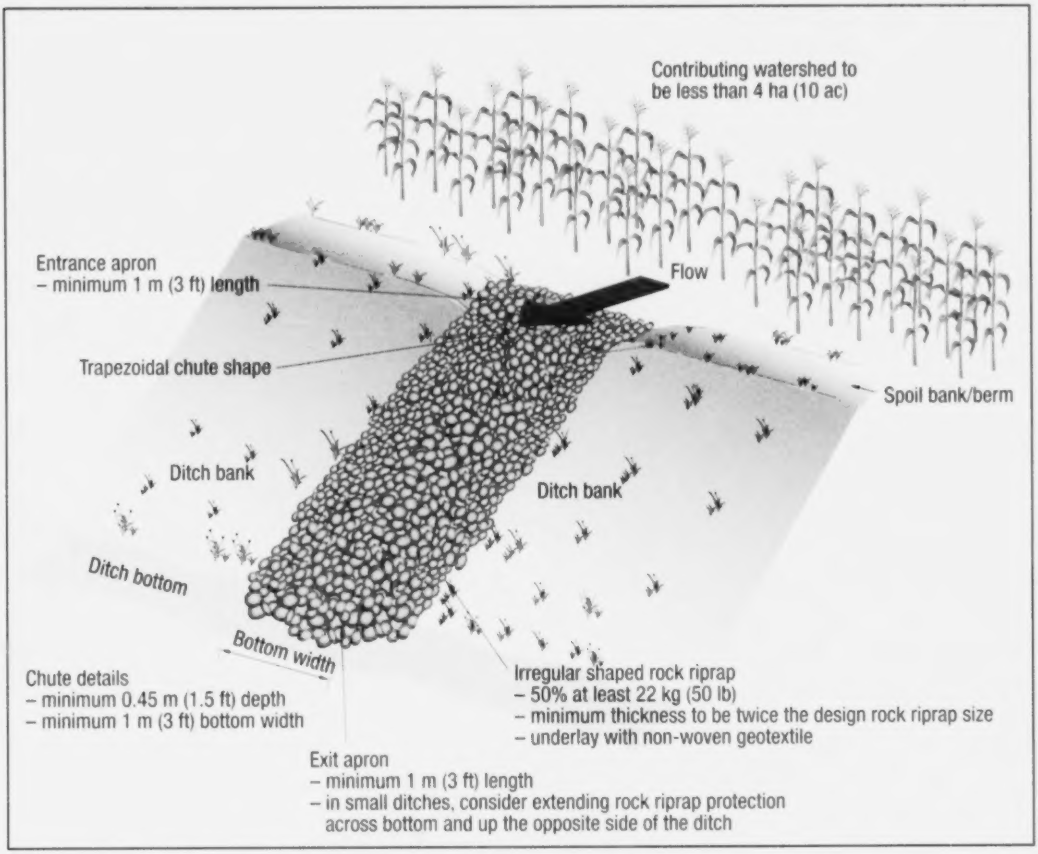


Figure 4.5. Ditch Bank Protection Using a Small Rock Chute Spillway

Drop Pipe Inlets

Drop pipe inlets or special surface water inlets are used to introduce surface flows into an open ditch. Many companies prefabricate different types of catch basins that do a good job when properly selected and installed. The trash guard, riser pipe size, outlet pipe size and outlet protection are all points to consider when installing a drop inlet catch basin. Appendix D lists commercial materials which can be purchased for this purpose. The sizing criteria for catch basins is in Section 4.3.2 or Section 4.5, Tile/Surface Water Inlet System.

Small Chute Spillway

The small chute spillway drop structure is designed to have a slope equivalent to the bank slope of the receiving ditch so field operations can be performed parallel to the ditch bank without undue obstruction. As with any rock riprap, design a small chute spillway as shown in Section 4.3. There may be situations – contributing watershed of less than 4 ha (10 ac) and limited space – when a simpler approach can be taken to the full design of a rock chute spillway. While the overall look to the spillway mimics Figure 4.8, dimensions are compressed with shorter entrance and exit aprons (minimum 1 m (3 ft)) and a chute slope that generally follows that of the ditch bank. The minimum sizing recommended is 0.45 m (1.5 ft) depth with 2:1 side slopes and a 1 m (3 ft) bottom width. Although a 4:1 chute slope is recommended, it may be as steep as 2:1 where very low flows are anticipated. Figure 4.8 provides general layout and installation details.

Other considerations:

- Underlay the structure with a non-woven geotextile, securely keyed in around the entire structure.
- Always account for overflow and direct excess water around the berm to protect its integrity.
- Use adequately sized and irregularly shaped rock riprap with 50% of the riprap weighing at least 22 kg (50 lb) and ensure the riprap thickness is at least twice the design rock riprap size.
- Consider protecting the ditch bank on the opposite side of the chute.
- Obtain approval from the local municipality to carry out work in a municipal drain and/or a roadside ditch.

For large surface flows, such as those flowing from a grassed waterway, see Section 4.3.1 for further design information.

Lateral Seepage

Many ditch bank failures are caused by lateral seepage. This type of phenomenon is vividly seen when an overburden of sand rests on an impermeable clay layer. If a ditch is constructed below the interface of the two layers, water will easily move down through the sand and then laterally out into the ditch at the clay layer. This seepage causes failures in the bank called sloughing. Two methods of controlling the problem are in use:

Interceptor Drain – Install 1.5-6 m (5-20 ft) back from the ditch and deep enough to penetrate the impervious layer to collect flows before they reach the ditch bank. The drain can be as simple as a regular 100 mm (4 in.) tile or as complicated as filter enclosed French drains.

Rock Riprap Protection of the Toe of the Ditch – Also prevents ditch failures due to lateral seepage. A filter material (geotextile) properly placed under properly-sized rock riprap permits water at the impermeable layer to escape through the bank without allowing the soil to move. This method often costs more than an interceptor tile giving it limited application.

Watch for areas of potential seepage problems and include a method of control in the design.

Berms

Berms – along with ditch bank seeding – have the potential to play an important role in solving ditch bank washout problems.

The majority of washouts are caused by concentrated surface flows entering the ditch over the ditch bank at areas where no protection is provided. Most structures installed to provide a safe entrance of water into the channel require the inclusion of a berm to produce a complete design.

The berm itself is a raised area of ground high enough to intercept surface flows and assist in directing them to a safe outlet. On very flat land the berm should be continuous on both sides of the drain. Berms don't need to be very wide – 1 m (3 ft) is sufficient to intercept most flows. Increase the width if the berm access is needed for maintenance operations. Grade the berm to allow easy clipping for weed control. Berm height depends on topography, volume of water to be intercepted and size of the outlet structure. Further details on berm construction are in Section 4.5, Water and Sediment Control Basins. Rolling land often has natural depressions that collect surface runoff, resulting in larger acreages directed to one point. Construct berms in these areas to traverse the depressed area and blend into the landscape at each end of the depression.

Engineers and drainage superintendents should consider the construction of berms as part of new construction and maintenance projects. Berms with appropriate outlets for the collected flows provide a cost effective method of solving many ditch bank washout problems.

Buffer Strips

A buffer strip, as the name implies, buffers the activities of one area from another. In connection with ditches, buffer strips are normally adjacent to the ditch bank and planted with permanent vegetation to discourage the operations of tillage equipment in close proximity to the bank itself.

The buffer strip may help filter soil particles, but this is generally thought to be of minimal value. The deep roots of a well established buffer strip – together with well established ditch bank vegetation – will withstand the forces of small over-the-bank flows.

A good buffer strip, like a berm, is raised to intercept flows. Ensure the buffer strip is wide enough for clipping to control weed growth or provide access for ditch maintenance equipment. Seeding recommendations for buffer strips are included in Section 3.1.

Channel Bends

Channel bends are often an area of severe erosion. Erosion potential is influenced by the radius of the bend, velocity of water, depth of flow and soil type. *Design and Construction Guidelines for Work under the Drainage Act, 1980* states that as a general guideline, "curves of radii smaller than $40\sqrt{A}$ (where A is waterway end area) tend to be destructive and scouring due to erosion may be expected".

The dimensions of a typical Ontario ditch may be 1 m (3 ft) bottom, 1.5 m (5 ft) depth and 2:1 side slopes. Using the above criteria, the radius of the curve should be approximately 100 m (325 ft) for the water to follow the curve with no detrimental effects.

This type of curvature is rarely seen in typical ditches that follow property lines. As a result, consider extra protection on all 90° turns in drainage channels. Rock riprap is the most common material used to add extra protection. The exact design of rock riprap protection can be complicated. Consult designers experienced in this type of design on large watercourses subject to high velocity and great depth of flow.

The information on rock riprap in Section 3.2 provides some design guidelines for small drainage ditches. In most cases, blast rock – which is readily available – has the size and weight characteristics to provide protection for the normal ditch. The installation of this rock is the key. When selecting rock, eliminate stones greater than 300 mm (12 in.) in diameter if possible. If using a random mixture of large and fine particles, a layered effect is important to ensure there are no voids upon installation. Key the rock riprap into the bottom of the ditch with a thickness of 1.5 to 2.0 times the diameter of the largest particles. Geotextile helps ensure the integrity of the design.

The outside of the bend is the only area that normally requires protection. A small area of rock riprap in the outside corner will probably have little effect on controlling the erosion. Extend the rock riprap up and downstream far enough to provide protection around the complete bend. Be sure the downstream protection goes well beyond the bend.

Culvert Protection

In most ditches, the culvert is a restriction from the point of view of cross-sectional area compared to the channel itself. Like fitting a square box in a round hole, deformation must happen to make it possible. Some turbulence develops whenever water has to deform from a trapezoidal-shaped channel to flow through a round culvert. Protect the upstream entrance wall from turbulence and the impact forces from ice flows, and protect the downstream end from back currents. The velocity of water normally increases through the length of the culvert and can cause downstream scouring and back currents that affect the downstream endwall. Some flow effects are reduced by slightly over-sizing the culvert and burying 10% to 20% of it below the channel bed. This also helps fish move through the pipe.

So called "hand placed" rock riprap is the normal protection used in many parts of Ontario. Other materials to use – depending on availability – include sacked concrete and wood timbers. Ensure the endwall is strong enough and heavy enough to withstand the impact forces of floating ice and debris. Use material that's flexible enough to self adjust if moved by impact or frost heave. Avoid large voids between particles of rock riprap or other material that can result in erosion of the material behind the protection. In choosing rock riprap – whether placed by hand or machine – pick rock pieces that will interlock tightly together.

An alternative to straight endwalls with rock riprap protection is to use longer culverts with flat end slopes from the top of the crossing to the invert of the culvert. Establishing grass on this embankment will provide protection. This method is practical for culverts of smaller diameter.

If possible, place culverts in straight sections of the channel rather than on curves. Proper alignment alleviates many of the problems associated with culvert washouts.

Tile Outfall Protection

Drainage outfalls are another area of potential erosion in ditches. The degree of tile outfall protection and the type of outfall installed depends on the area of the province. If floating ice is a problem, the end pipe should not protrude too far beyond the ditch bank. Install the outfall in locations where surface flows don't tend to collect. If it's imperative to install a tile outfall in such a location, ensure the tile drainage contractor makes provisions to handle the surface and subsurface flow. One solution is a berm across the depression with a catch basin and end pipe large enough to handle both flows. In either instance, protect ditch banks below the outfall pipe to prevent scouring.

What appears to be an insignificant problem – and easy to solve – in effect is quite difficult. The only answer is to coordinate efforts by tile drainage contractors and drainage superintendents. For example, a contractor providing a well-protected outfall for the farmer could have the work destroyed when the drainage superintendent cleans the drain and flattens the side slope. The tile contractor must be in constant communication with the appropriate drainage superintendent so ownership requirements are met and work is not duplicated.

The most common material used to protect drainage outfalls is rock riprap. Square field stones are satisfactory if properly placed and properly keyed to prevent slipping. Piling stones only on top of the outfall with none below or without underlaying it with non-woven geotextile serves no practical purpose. The stones will wash away over time making the problem worse.

Steep Grades in Channels

The problem of channels constructed in steeply graded areas is less prevalent than the problem of too little grade. A common rule is that if the channel has a slope greater than 0.5%, the designer needs a method to control scouring of the ditch bottom. On channels with slopes greater than this, there could be a problem depending upon soil type, velocity and depth of flow. The principles of grassed waterway design may be tried, but in most cases the depth of flow is too high and resulting velocity too great to allow for protection by a simple grass cover. By their nature, ditches are narrow and deep – rather than shallow and wide – due to tile drainage requirements and restrictions imposed by farmers about the amount of land taken. If scouring the ditch bottom is a problem, use one of the following two common methods.

Drop Structures – Using drop structures is an economical way to prevent scouring in ditches with grades in the 0.5% range. Install these structures at intervals so that different reaches of the channel are flattened with the drop being sudden at specific protected areas. Use gabion baskets and in-channel rock chutes for this purpose. Further design of drop structures is covered in Section 4.3 Drop Structures.

Rock Riprap Lining of Channel – In ditches where the grade is greater than 1%, it's often more economical to line the complete channel rather than provide grade control structures. Use rock riprap that's sized and placed in accordance with velocity and depth of flow. Section 3.2 gives design methods for choosing rock riprap for this purpose.

Fencing of Ditches

Livestock cause a great deal of damage when allowed access to watercourses. They destroy grass cover on the ditch bank, leaving the bank susceptible to erosion. Soil is physically tramped down the bank into the stream bottom, causing sedimentation that interferes with the proper operation of the drain and increases maintenance costs. Water quality is also affected with the increased sediment and bacterial load due to the livestock. Fencing watercourses is a logical solution to these problems. The OMAFRA Factsheet, *Fencing of Watercourses to Control Erosion*, Order No. 00-049, provides more details on choosing a fencing system.

Use a buffer strip or buffer strip/berm combination in conjunction with fencing to avoid the area between the bank and fence from becoming a haven for weed growth. An important factor in the overall stability of a watercourse is the land use activity taking place immediately adjacent to it. Experience has shown that maintaining 2-5 m (6.5-16 ft) of this critical area in permanent grass cover considerably increases the watercourse stability. Maintain this important grass cover by avoiding activities on the buffer strip that include plowing, cultivating and planting row or cereal crops.

Maintenance

Any open ditch that's to function as intended requires some maintenance to prevent problems. Fallen trees or silt buildup can deflect the flow, causing damage to the bank. Any structures in a drain – including drop structures, rock riprap protection at bends, culverts and tile outfalls – are potential sources of problems if not properly designed, installed and maintained. Immediately correct any failures that occur as a minor problem can cuickly turn into a major one. The most important factor is to maintain a good vegetative cover.

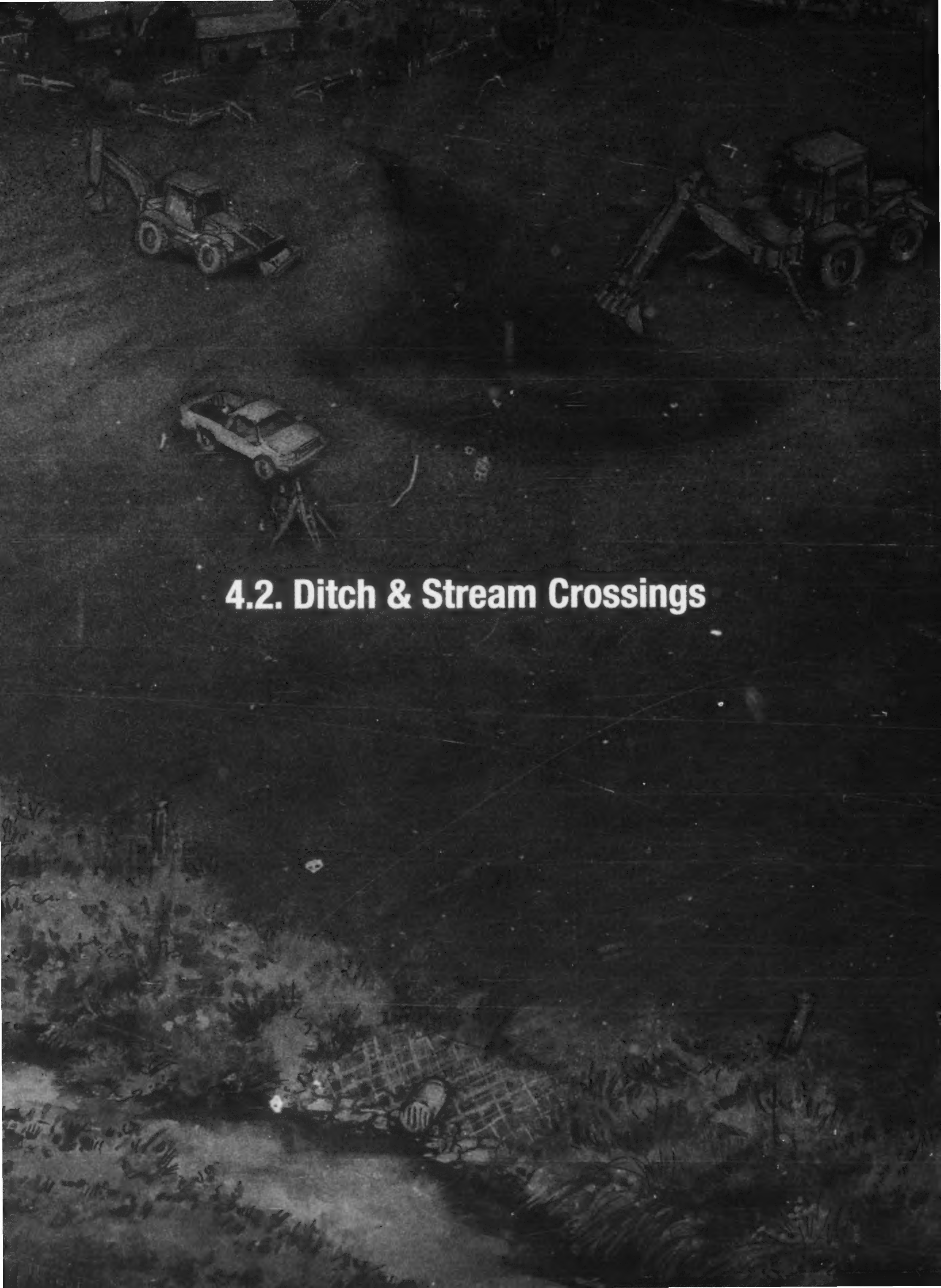
Reseed areas where seeding didn't catch, has been damaged or died off. Periodic clipping of ditch banks and buffer strips allows the drains to operate more efficiently and controls the growth of weeds and cattails.

Local municipalities are responsible for maintenance of municipal drains. Call the local drainage superintendent if problems occur.

Timing

Any work in or around a natural watercourse or municipal drain can affect fish and fish habitat. Contact the local municipality, conversation authority or Ministry of Natural Resources office for advice and possible approval before undertaking any work in or around water. Appendix C outlines legislation and regulations that may apply.

Other timing-related factors to consider in ditch construction are the need to avoid periods of heavy runoff and the most suitable grass establishment periods.



4.2. Ditch & Stream Crossings

4.2 Low Level Ditch and Stream Crossings

There are two general types of stream crossings – bank level crossings and low level crossings. With bank level crossings, traffic traverses the stream at or above the same level as the top of the streambank. Low level crossings permit farm vehicles to cross at or near the level of the stream bed.

The low level crossing requires a gradual descent from the level of the bank to the crossing structure, followed by an ascent back to the level of the bank again. Following are two types of low level crossings.

Low Flow Mid-level Crossing with Culverts – As the name implies, this type of crossing allows low flows to pass through the structure. Larger flows, such as those experienced during the spring runoff or large rainfall events, result in the structure being submerged. These crossings normally consist of one to several relatively small culverts designed with capacity to handle the small sustained flows evident during summer months. The crossing surface is provided by covering these culverts with an erosion-resistant material.

Bed Level Crossing or Ford – With this crossing, livestock, machinery and vehicles cross at the same level as the natural bed of the stream. All water in the stream passes over the structure. At a typical crossing it may be necessary to drive or walk through a few inches to a few feet of water.

Choosing a Type of Crossing

In determining the type of stream crossing that should be constructed (i.e. bank level or low level), the two main factors to be considered are the use of the crossing and economics.

Use of the Crossing – Crossings on farms can normally be broken into three categories.

- Bank level crossings, such as bridges and large culverts, provide daily access to the farm home and major production facilities. Design these crossings with the same hydraulic, structural and safety consideration that are used on a township road. Access to the farm home at any time of the year is imperative for the well being of the farm family and success of the farm business.
- Low flow mid-level crossings with culverts are used at certain stream or ditch crossings of secondary importance. A washout or other failure of these crossings wouldn't create a serious threat to the safety or livelihood of the farm family. These crossings are on main farm lanes used extensively during the spring to fall months. Structurally, design these crossings to carry the heaviest anticipated load. Hydraulically, design them slightly less than for bank level crossings. Give preference to bank level crossings since considerable traffic will use the structure at certain times of year, while considering that economics may dictate the use of a well designed low flow mid-level crossing with culverts.
- Bed level crossings are used for areas of the farm requiring limited access. Crossings to fields may be necessary only two or three times per year – during spring tillage and planting, summer spraying and harvesting, and fall harvesting and/or tillage. A bed level crossing may be the best choice for these situations, depending on factors such as stream flow conditions and economics.

Economics – For most small watercourses (requiring a 1.2 m (4 ft) diameter or smaller culvert to handle the design flow), a culvert type bank level crossing is probably most economical, even with limited use. In watercourses larger than this – such as large ditches, creeks and rivers – consider installing low level crossings. When making a final economic decision, consider the amount of use, the stream flow conditions and the final cost of the crossing structure itself. With these things in mind, there will be times to use low level crossings in relatively small watercourses when level access is required on a very limited basis, and times to use low level crossings in major rivers when bank level crossings would be economically prohibitive.

Choosing a Type of Low Level Crossing

Low flow mid-level crossings with culverts are considerably more expensive than bed level or ford type crossings. The extra cost is in the purchase of multiple culverts or other structures to pass the low flow, and extra erosion protection upstream, downstream and on the driving surface of the crossing itself. The economics and the use of the crossing, along with stream flow conditions, are most important factors when choosing a type of low level crossing. Stream flow conditions are important as there's a limit to how much water can be driven through.

Design of Bed Level Crossings

In designing and constructing a bed level crossing, consider the following three factors.

Slope and Size of Driving Surface – To facilitate easy crossing by farm machinery, slope the approaches at a grade of 8 horizontal:1 vertical. If the stream has a depth below the bank of 3 m (10 ft), start the approach 25 m (82 ft) back from the edge of the stream. Base the width of the driving surface on the width of equipment wheel base that's using it. Remember to factor in the overhang or offset position of some farm equipment. Consider a 4 m (13 ft) driving surface as a minimum width, with a 5 m (16 ft) width more suitable in most cases.

Bank Slopes on Watercourses and Approaches – The condition of the banks on the existing watercourse gives an indication of the slopes to use on the approaches. If the banks are in a very stable condition with no slumping or undermining, use the same slopes in the approaches. If there are serious erosion problems on the existing stream, consider sloping the banks of the approaches in a similar way as recommended for open ditch construction. Seed all new earth cuts immediately after construction to establish some erosion prevention vegetation.

Base of Driving Surface of Approaches and Stream Bed – Construct the base from concrete, concrete barn slats, interlocking concrete blocks or rock riprap. If using rock riprap, determine the size by methods in Section 3.2. Large size rock riprap may not be acceptable, especially if cattle are required to cross. Concrete and concrete interlocking blocks can both be used, but will often substantially increase the cost. Concrete is an inflexible material without the healing qualities of rock riprap or interlocking blocks. Seek additional advice before installing a concrete or interlocking block bed level crossing. In the section of the approach that's remote from the crossing, use a good layer of 75 mm (3 in.) minus stone, similar to that used in most road construction. Figure 4.6 shows some details of a good bed level crossing or ford.

Design of Low Flow Mid-Level Crossings with Culverts

The first two factors in designing bed level crossings also apply to low flow mid-level crossings with culverts. The main decision on the design of a low flow crossing is the decision about how much water goes through the structure and how much goes over it. It's generally difficult to estimate low flow, so make a good estimation based on past experience. On natural watercourses, flow data may be available. If so, consider the peak flow generated from a 1.2 year runoff event as a suitable design flow rate. Local conservation authorities may also have flow information. Another option is to source someone experienced in flow determination based on watercourse features to survey the area of the proposed crossing and determine the design flow needs.

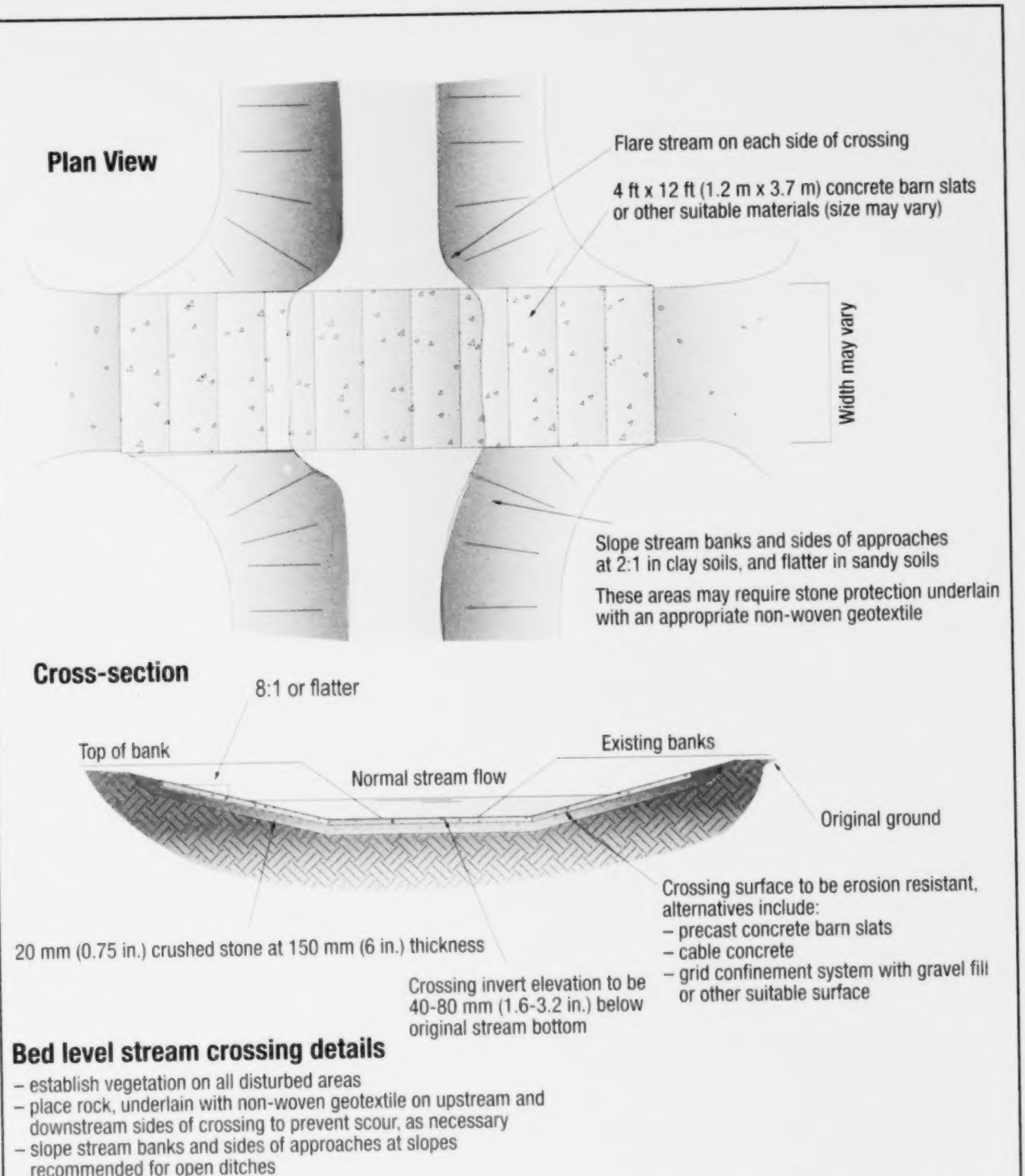


Figure 4.6. Bed Level Stream Crossing

Since the driving surface above the low flow mid-level structure is very susceptible to erosion, pay considerable attention to protecting this surface. Low flow mid-level structures cause a restriction in the channel during times when the flow must pass over it. This restriction can cause extra turbulence, so provide extra erosion protection downstream and upstream of the structure. Seek assistance from people with expertise in this area before spending a lot of money on low flow mid-level crossings. Depending on the nature of the watercourse, permits or approval may be required prior to construction. Consult the local drainage superintendent, local conservation authority or the Ministry of Natural Resources about permits and approval required.

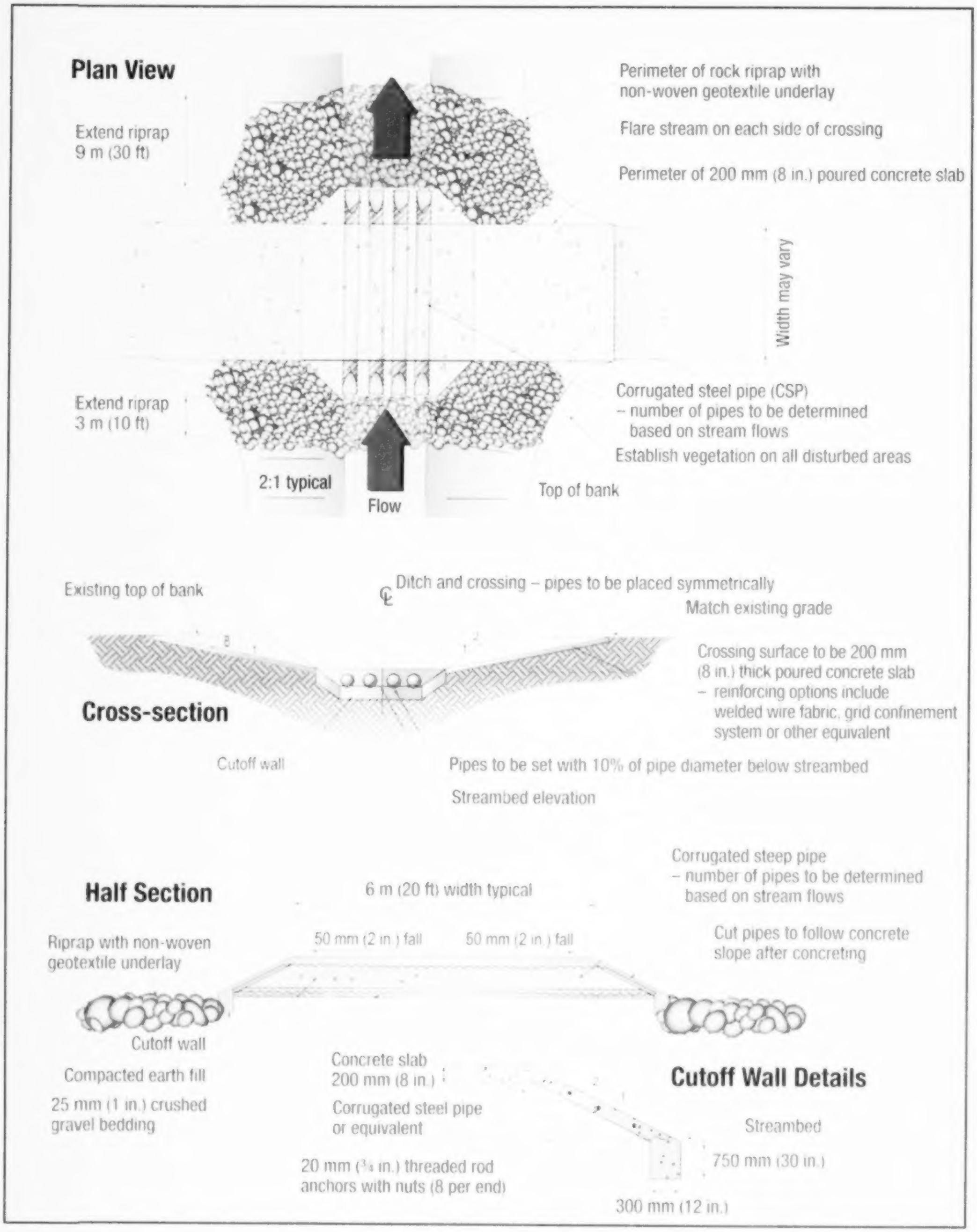


Figure 4.7. Low Flow Mid-level Stream and Ditch Crossing with Culverts

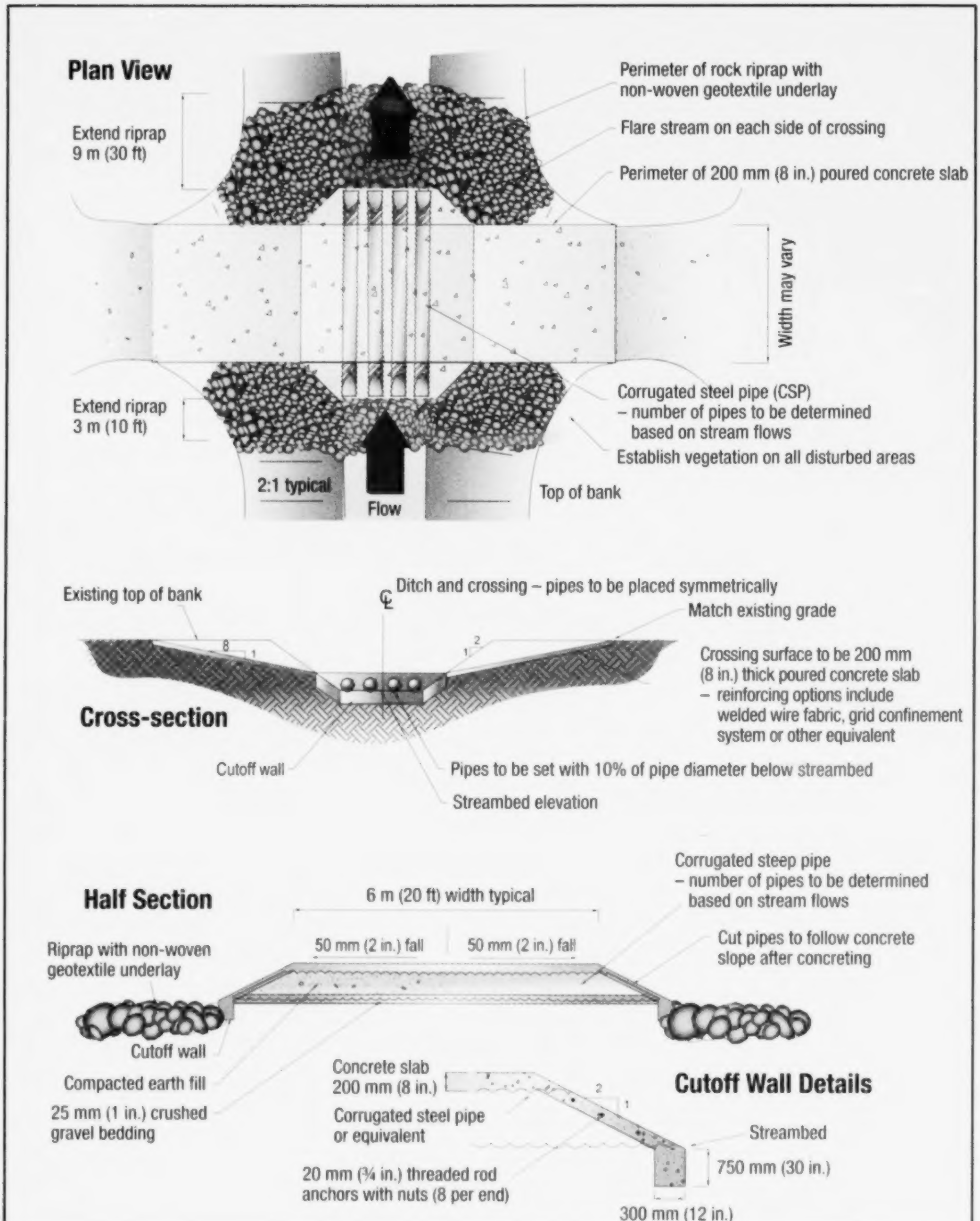
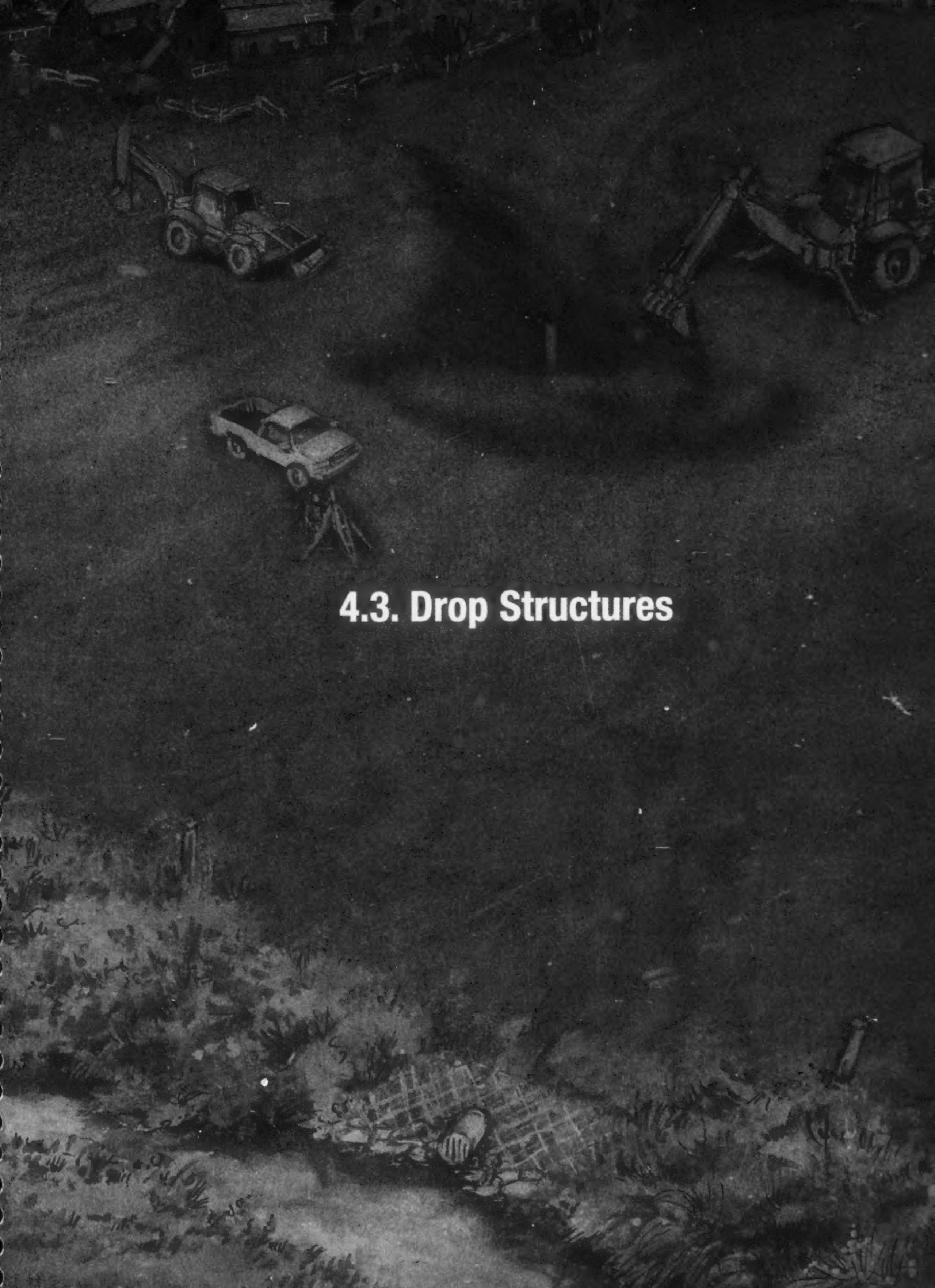


Figure 4.7. Low Flow Mid-level Stream and Ditch Crossing with Culverts



4.3. Drop Structures

4.3 Drop Structures

Drop structures allow a concentration of surface water to drop in elevation in a controlled manner.

Conditions Where Applicable

Drop structures are used in locations where normal vegetation can't withstand eroding forces such as where there's a sudden drop in topography. Example locations include old fence lines, open drains or beside natural watercourses.

Types of Drop Structures Available

Several types of structures are commonly used in Ontario agriculture and are covered in detail in this section.

4.3.1 Chute Spillways

Chute spillways carry a concentrated flow of water down an inclined structure. These spillways – constructed with rock riprap, interlocking concrete blocks, gabion baskets, mats or other materials – are often located at old fence lines or at entrance points to ditches or streams. They blend in well with grassed waterways since their shapes are similar.

Flow Range

The enclosed charts give a flow range of 0.28-2.8 m^3/s (10-100 ft^3/s). Seek professional assistance for flows greater than those noted.

Vertical Drop Range

Tables 4.12-M to 4.14-M (4.12-I to 4.14-I) give a drop range from 0.3-1.5 m (1-5 ft). Seek professional assistance for vertical drops greater than those noted.

Advantages of a Rock Chute

- provides immediate protection after construction
- often fits the topography with little land shaping
- high flow capacity

Disadvantages of a Rock Chute

- properly sized and shaped rock riprap is expensive to obtain in many parts of Ontario
- chute may jut out a long distance from the ditch into the field

Types Available

Many materials are used in the construction of chutes, as discussed in previous sections of this manual. The majority of this section will look at rock chute design (Figure 4.8). Other materials are addressed briefly at the end of the section.

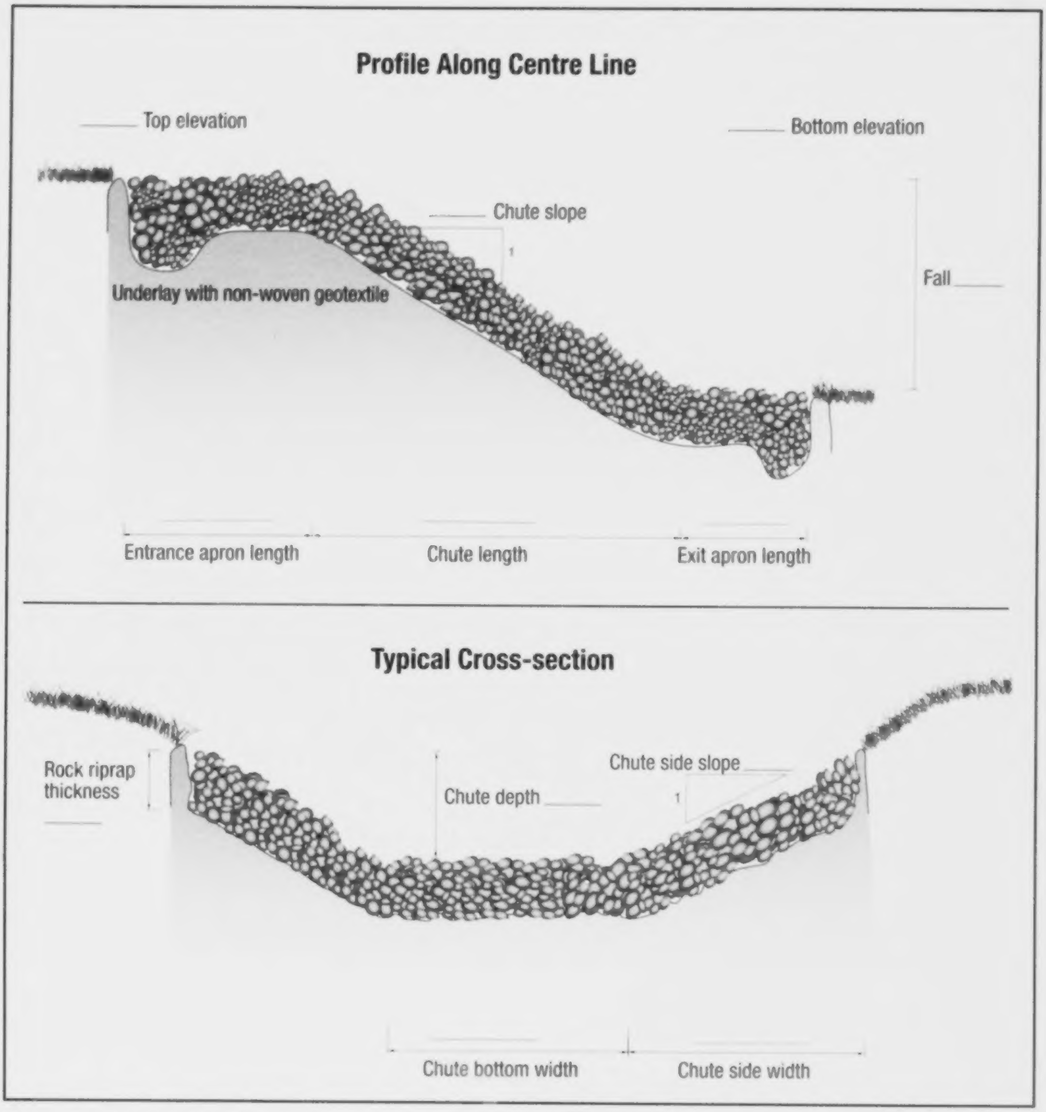


Figure 4.8 Rock Chute

Design Criteria

- Entrance apron length is a minimum of three times the vertical drop or 3 m (10 ft), whichever is greater.
- Exit apron length is a minimum of twice the vertical drop.
- Rock riprap depth is a minimum of 450 mm (18 in.) or twice the design riprap size (whichever is greater).
- Use adequate filter cloth underneath the rock riprap. Anchor this cloth at least 300 mm (12 in.) vertically at the edges of the chute to prevent undermining.
- Use a rock riprap size with 50% of the individual pieces weighing 22 kg (50 lb) or more and the maximum size piece weighing 90 kg (200 lb) or more. Rock riprap should be angular in shape. Using information discussed in Section 3.2 Rock Riprap, 300-400 mm (12-15 in.) minus stone is adequate.

Design Steps

1. Determine expected peak flow (Q)(See Section 2.3).
2. Determine vertical drop or fall (F).
3. Determine the distance it takes to obtain the required fall.
4. Choose the chute slope. To minimize land shaping often the chute slope chosen is the same ratio as determined in steps 2 and 3.
5. Choose a chute side slope. Using Tables 4.12-M to 4.14-M (4.12-I to 4.14-I), choose from three side slopes 2:1, 3:1 or 4:1. A particular side slope is often used to correspond with the shape of the erosion control system above or below the chute.
6. Flow (Q) in the charts is known from step 1 and side slope from step 5. Consider the highest velocity for economics, unless high safety is required. Use this information to choose the bottom width and obtain the depth of the chute (D).
7. Complete the specific dimensions of the chute and enter into the plan. Use the design criteria section for sizing requirements. See the example section for detailed instructions on determining the dimensions. If the dimensions are not satisfactory, use the charts to obtain another combination of dimensions.

Table 4.12-M. Rock Chute Design Chart: Chute Depth in Metres (includes 0.3 m freeboard) when Chute Slope is 4:1 (25%)

Flow (Q) m^3/s	Side Slope 2:1				Side Slope 3:1				Side Slope 4:1			
	Bottom Width (m)				Bottom Width (m)				Bottom Width (m)			
	1.0	1.2	1.5	1.8	1.0	1.2	1.5	1.8	1.0	1.2	1.5	1.8
0.28	0.50	0.50	-	-	0.50	0.50	-	-	0.50	0.50	-	-
0.42	0.55	0.55	0.50	-	0.55	0.50	0.50	-	0.55	0.50	0.50	-
0.57	0.60	0.55	0.55	-	0.55	0.55	0.55	-	0.55	0.55	0.55	-
0.71	-	0.60	0.55	0.55	0.60	0.60	0.55	0.55	0.60	0.55	0.55	0.55
0.85	-	-	0.60	0.55	-	0.60	0.60	0.55	0.60	0.60	0.55	0.55
0.99	-	-	-	-	-	-	0.60	0.60	0.60	0.60	0.60	0.55
1.13	-	-	-	-	-	-	-	0.60	0.65	0.60	0.60	0.60

Note: To reduce the size of the chart the actual chute depth was assumed to be equal to the entry depth. This is a conservative estimate. Consult an OMAFRA engineer for charts with separate depths.

Table 4.12-I. Rock Chute Design Chart: Chute Depth in Feet (includes 1 ft freeboard) when Chute Slope is 4:1 (25%)

Flow (Q) ft^3/s	Side Slope 2:1				Side Slope 3:1				Side Slope 4:1			
	Bottom Width (ft)				Bottom Width (ft)				Bottom Width (ft)			
	3	4	5	6	3	4	5	6	3	4	5	6
10	1.6	1.5	-	-	1.6	1.5	-	-	1.5	1.5	-	-
15	1.8	1.7	1.6	-	1.7	1.6	1.6	-	1.7	1.6	1.6	-
20	1.9	1.8	1.7	-	1.8	1.8	1.7	-	1.8	1.7	1.7	-
25	-	1.9	1.8	1.8	1.9	1.9	1.8	1.7	1.9	1.8	1.7	1.7
30	-	-	1.9	1.8	-	1.9	1.9	1.8	2.0	1.9	1.8	1.8
35	-	-	-	-	-	-	1.9	1.9	2.0	2.0	1.9	1.8
40	-	-	-	-	-	-	-	1.9	2.1	2.0	2.0	1.9

Note: To reduce the size of the chart the actual chute depth was assumed to be equal to the entry depth. This is a conservative estimate. Consult an OMAFRA engineer for charts with separate depths.

Table 4.13-M Rock Chute Design Chart: Chute Depth in Metres (includes 0.3 m freeboard) when Chute Slope is 5:1 (20%)

Flow (Q) m^3/s	Side Slope 2:1				Side Slope 3:1				Side Slope 4:1				
	Bottom Width (m)				Bottom Width (m)				Bottom Width (m)				
	1.0	1.2	1.5	1.8	1.0	1.2	1.5	1.8	1.0	1.2	1.5	1.8	2.5
0.28	0.50	0.45	-	-	0.50	0.45	-	-	0.45	0.45	-	-	-
0.42	0.55	0.55	0.50	-	0.55	0.50	0.50	-	0.55	0.50	0.50	-	-
0.57	0.60	0.55	0.55	-	0.55	0.55	0.55	-	0.55	0.55	0.55	-	-
0.71	0.60	0.60	0.55	0.55	0.60	0.60	0.55	0.55	0.60	0.55	0.55	0.55	-
0.85	0.65	0.60	0.60	0.55	0.60	0.60	0.60	0.55	0.60	0.60	0.55	0.55	-
0.99	-	0.65	0.60	0.60	0.70	0.60	0.60	0.60	0.65	0.60	0.60	0.55	-
1.13	-	-	0.65	0.60	-	0.65	0.60	0.60	0.65	0.60	0.60	0.60	-
1.27	-	-	-	0.65	-	0.70	0.65	0.60	0.70	0.65	0.60	0.60	-
1.42	-	-	-	-	-	-	0.70	0.65	0.70	0.70	0.65	0.60	0.60
1.70	-	-	-	-	-	-	-	-	-	0.70	0.7	0.65	0.60

Note: To reduce the size of the chart the actual chute depth was assumed to be equal to the entry depth. This is a conservative estimate. Consult an OMAFRA engineer for charts with separate depths.

Table 4.13-I. Rock Chute Design Chart: Chute Depth in Feet (includes 1 ft freeboard) when Chute Slope is 5:1 (20%)

Flow (Q) ft^3/s	Side Slope 2:1				Side Slope 3:1				Side Slope 4:1				
	Bottom Width (ft)				Bottom Width (ft)				Bottom Width (ft)				
	3	4	5	6	3	4	5	6	3	4	5	6	8
10	1.6	1.5	-	-	1.6	1.5	-	-	1.5	1.5	-	-	-
15	1.8	1.7	1.6	-	1.7	1.6	1.6	-	1.7	1.6	1.6	-	-
20	1.9	1.8	1.7	-	1.8	1.8	1.7	-	1.8	1.7	1.7	-	-
25	2.0	1.9	1.8	1.7	1.9	1.9	1.8	1.7	1.9	1.8	1.7	1.7	-
30	2.1	2.0	1.9	1.8	2.0	1.9	1.9	1.8	2.0	1.9	1.8	1.8	-
35	-	2.1	2.0	1.9	2.2	2.0	1.9	1.9	2.1	2.0	2.0	1.8	-
40	-	-	2.1	2.0	-	2.1	2.0	1.9	2.1	2.0	2.0	1.9	-
45	-	-	-	2.1	-	2.2	2.1	2.0	2.2	2.1	2.0	2.0	-
50	-	-	-	-	-	-	2.2	2.1	2.3	2.2	2.1	2.0	1.9
60	-	-	-	-	-	-	-	-	-	2.3	2.2	2.1	2.0

Note: To reduce the size of the chart the actual chute depth was assumed to be equal to the entry depth. This is a conservative estimate. Consult an OMAFRA engineer for charts with separate depths.

Table 4.14-M. Rock Chute Design Chart: Chute Depth in Metres (includes 0.3 m freeboard) when Chute Slope is 6:1 (16.7%)

Flow (Q) m^3/s	Side Slope 2:1				Side Slope 3:1				Side Slope 4:1				
	Bottom Width (m)				Bottom Width (m)				Bottom Width (m)				
	1	1.2	1.5	1.8	1	1.2	1.5	1.8	1	1.2	1.5	1.8	2.5
0.28	0.50	0.45	-	-	0.50	0.45	-	-	0.45	0.45	-	-	-
0.42	0.55	0.55	0.50	-	0.55	0.50	0.50	-	0.55	0.50	0.50	-	-
0.57	0.55	0.55	0.55	0.50	0.55	0.55	0.55	0.50	0.55	0.55	0.55	-	-
0.71	0.60	0.60	0.55	0.55	0.60	0.60	0.55	0.55	0.60	0.55	0.55	0.55	-
0.85	0.65	0.60	0.60	0.55	0.60	0.60	0.60	0.55	0.60	0.60	0.55	0.55	-
0.99	-	0.65	0.60	0.60	0.65	0.65	0.60	0.60	0.65	0.60	0.60	0.55	-
1.13	-	-	0.65	0.60	0.70	0.65	0.60	0.60	0.65	0.60	0.60	0.60	-
1.27	-	-	-	0.65	0.70	0.70	0.65	0.60	0.70	0.65	0.60	0.60	0.60
1.42	-	-	-	-	-	0.70	0.70	0.65	0.70	0.70	0.65	0.60	0.60
1.70	-	-	-	-	-	-	-	0.70	0.75	0.70	0.70	0.65	0.60
1.98	-	-	-	-	-	-	-	-	0.80	0.75	0.70	0.70	0.65
2.27	-	-	-	-	-	-	-	-	0.80	0.80	0.75	0.70	0.70
2.55	-	-	-	-	-	-	-	-	0.85	0.80	0.80	0.75	0.70
2.83	-	-	-	-	-	-	-	-	0.85	0.80	0.80	-	-

Note: To reduce the size of the chart the actual chute depth was assumed to be equal to the entry depth. This is a conservative estimate. Consult an OMAFRA engineer for charts with separate depths.

Table 4.14-I. Rock Chute Design Chart: Chute Depth in Feet (includes 1 ft freeboard) when Chute Slope is 6:1 (16.7%)

Flow (Q) ft^3/s	Side Slope 2:1				Side Slope 3:1				Side Slope 4:1				
	Bottom Width (ft)				Bottom Width (ft)				Bottom Width (ft)				
	3	4	5	6	3	4	5	6	3	4	5	6	8
10	1.6	1.5	-	-	1.6	1.5	-	-	1.5	1.5	-	-	-
15	1.8	1.7	1.6	-	1.7	1.6	1.6	-	1.7	1.6	1.6	-	-
20	1.8	1.8	1.7	1.6	1.8	1.8	1.7	1.6	1.7	1.7	1.7	-	-
25	2.0	1.9	1.8	1.7	1.9	1.9	1.8	1.7	1.9	1.8	1.7	1.7	-
30	2.1	2.0	1.9	1.8	2.0	1.9	1.9	1.8	2.0	1.9	1.8	1.6	-
35	-	2.1	2.0	1.9	2.1	2.1	1.9	1.9	2.1	2.0	1.9	1.8	-
40	-	-	2.1	2.0	2.2	2.1	2.0	1.9	2.1	2.0	2.0	1.9	-
45	-	-	-	2.1	2.3	2.2	2.1	2.0	2.2	2.1	2.0	2.0	1.9
50	-	-	-	-	-	2.2	2.2	2.1	2.3	2.2	2.1	2.0	1.9
60	-	-	-	-	-	-	-	2.2	2.4	2.3	2.2	2.1	2.0
70	-	-	-	-	-	-	-	-	2.5	2.4	2.3	2.2	2.1
80	-	-	-	-	-	-	-	-	2.6	2.5	2.4	2.3	2.2
90	-	-	-	-	-	-	-	-	2.7	2.6	2.5	2.4	2.3
100	-	-	-	-	-	-	-	-	2.7	2.6	2.6	-	-

Note: To reduce the size of the chart the actual chute depth was assumed to be equal to the entry depth. This is a conservative estimate. Consult an OMAFRA engineer for charts with separate depths.

Installation Steps

1. Complete a survey and stake out the location and elevation of the chute. Often the chute is constructed before other erosion control or drainage systems, such as grassed waterways or open ditches, are installed.
2. Complete the base shape of the rock chute. Remember that at least 450 mm (18 in.) – or twice the design rock riprap thickness – will be added to the base. It's better to remove earth than add earth to avoid problems with settlement and tracking of the water along the recently moved fill.
3. Install the filter cloth, placing it under the entire structure. It's important to notch the cloth at least 300 mm (12 in.) into the native soil at all edges of the mat. If using loose fill, consider cutoff walls on long chutes to prevent water from tracking under the mat structure.
4. Install the rock riprap over the filter mat, ensuring that the filter material doesn't shift during installation. Use a uniform gradation of rock riprap.

Maintenance

- Watch for shifting rocks. Expect some initial movement of the rock riprap until it knits into shape. Add additional rock riprap, if needed, to the top of the structure to compensate for this movement. If the movement persists, consider a redesign to eliminate the problem.
- Watch for water tracking under the filter material. If this occurs, construct a cutoff wall immediately. This wall is ideally located at the beginning of the sloped area.
- Watch for water going around the structure, usually caused by entrance problems. It's extremely important to properly direct the water into the rock chute. This is achieved by minimizing changes to the water direction before the water enters the chute. The entrance part of the chute can also work as the transition area.
- Watch for erosion advancing towards the stabilizing toe of the revetment structure. If the toe is weakening by undermining, the rock will tend to slide with the help of gravity. Consider a redesign to eliminate the problem.
- Remove any tree saplings that may interfere with flow patterns.

Rock Chute Design Information Sheet

1. Watershed area			_____ ha	_____ ac
2. Average grade of watershed			_____ %	
3. Runoff curve number from Tables 2.2 – 2.4			_____	
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)			_____ m^3/s	_____ ft^3/s
5. Rock chute fall			_____ m	_____ ft
6. Horizontal distance to obtain chute fall			_____ m	_____ ft
7. Grade to fit $= \frac{(5)}{(6)} \times 100$	$\frac{\_\_\_\_\_ m}{\_\_\_\_\_ m} \times 100$	$\frac{\_\_\_\_\_ ft}{\_\_\_\_\_ ft} \times 100$	_____ %	
8. Type and size of input device				
9. Type and size of output device				
10. Chute slope from Tables 4.12-M to 4.14-M (4.12-I to 4.14-I)			_____ :1 or _____ %	
11. Side slope			_____ :1	
12. Bottom width			_____ m	_____ ft
13. Chute depth			_____ m	_____ ft
14. Chute width			_____ m	_____ ft
15. Total chute length			_____ m	_____ ft
16. Rock riprap to order for chute			_____ m^3	_____ yd^3
17. Additional rock riprap to order for transitions, curves, etc.			_____ m^3	_____ yd^3
18. Total rock riprap to order (16) + (17)			_____ m^3	_____ yd^3

Rock Chute – Example Problem #1

Determine the dimensions for a rock chute that meets the following requirements:

- design flow (Q) = 1.42 m^3/s (50 ft^3/s)
- grade to fit = 20%
- fall (F) = 1.2 m (4 ft)

A grassed waterway enters the top of the structure with a width of 12.2 m (40 ft) and depth of 0.4 m (1.2 ft). The rock chute exits into another grassed waterway with a similar width of 12.2 m (40 ft).

Solution

1. Use Table 4.13-M (4.13-I) as it uses the same grade to fit. Other tables could be used, but more earth-shaping would be required to meet the design criteria.
2. Find the necessary flow rate (Q) in the left hand column. At a flow rate of 1.42 m^3/s (50 ft^3/s), choose 3:1 or 4:1 side slopes. Since a grassed waterway is used top and bottom, consider the 4:1 side slope to minimize the change in watercourse shape.
3. Choose a bottom width from 1-2.5 m (3-8 ft) wide. To minimize the changes in the waterway shape, use the maximum bottom width of 2.5 m (8 ft) wide.
4. Find the chute depth (D), where the flow rate Q = 1.42 m^3/s (50 ft^3/s) intersects the column showing side slope 4:1, bottom width 2.5 m (8 ft). In this case the depth is 0.6 m (1.9 ft).
5. Determine the total width of the chute. Since a 4:1 side slope is used, the width of each side will be 4 x 0.6 = 2.4 m (7.6 ft). Since two sides and one bottom are required, the total width of the chute is 2 x 2.4 + 2.5 = 7.3 m (23.2 ft). This is still narrower than the grassed waterway of 12.2 m (40 ft), so have the entrance apron of the chute start at 12.2 m (40 ft) wide and end at 7.3 m (23.2 ft) wide. Conversely, the same must happen at the exit apron of the chute.
6. Determine the length of the entrance apron by the greater of three times the fall or 3 m (10 ft), so the length is 3 x 1.2 = 3.6 m (12 ft).
7. Determine the horizontal length of the actual chute by multiplying the chosen chute slope by the fall which is 5 x 1.2 = 6 m (20 ft).
8. Make the length of the exit apron twice the fall at 2 x 1.2 = 2.4 m (7.6 ft).
9. Determine the total length of the chute by adding the lengths of the three components together. For this example, it works out to 12 m (40 ft).
10. Work out the amount of rock to order. The overall chute is 7.3 m (23.2 ft) wide and 12 m (40 ft) long, creating a horizontal surface area of 87.6 m^2 (928 ft^2). However, the chute is not all in a horizontal plane. Allow for a 5% increase in area when ordering the rock, which works out to 92 m^2 (974 ft^2). From before, the rock is to be 0.45 m (1.5 ft) deep. The chute volume rock riprap required will be 92 x 0.45 = 41.4 m^3 (974 x 1.5 = 1,461 ft^3 or 54 yd^3). Addition of the transition rock of 7.6 m^3 (10 yd^3) gives a total of 49 m^3 (64 yd^3) to order.
11. Enter this information on Figure 4.9.

Rock Chute Design Information Sheet – Example Problem #1

1. Watershed area			N/A	N/A
2. Average grade of watershed				N/A
3. Runoff curve number from Tables 2.2 – 2.4				N/A
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)			1.42 m^3/s	50 ft^3/s
5. Rock chute fall			1.2 m	4 ft
6. Horizontal distance to obtain chute fall			N/A	N/A
7. Grade to fit = $\frac{(5)}{(6)}$ x 100	$\frac{\_\_\_ m}{m}$ x 100	$\frac{\_\_\_ ft}{ft}$ x 100		20%
8. Type and size of input device			Waterway – 12.2 m (40 ft) wide	
9. Type and size of output device			Waterway – 12.2 m (40 ft) wide	
10. Chute slope from Tables 4.12-M to 4.14-M (4.12-I to 4.14-I)				5:1 or 20
11. Side slope				4:1
12. Bottom width			2.5 m	8 ft
13. Chute depth			0.6 m	1.9 ft
14. Chute width			7.3 m	23.2 ft
15. Total chute length			12 m	40 ft
16. Rock riprap to order for chute			41.4 m^3	54 yd^3
17. Additional rock riprap to order for transitions, curves, etc.			7.6 m^3	10 yd^3
18. Total rock riprap to order (16) + (17)			49 m^3	64 yd^3

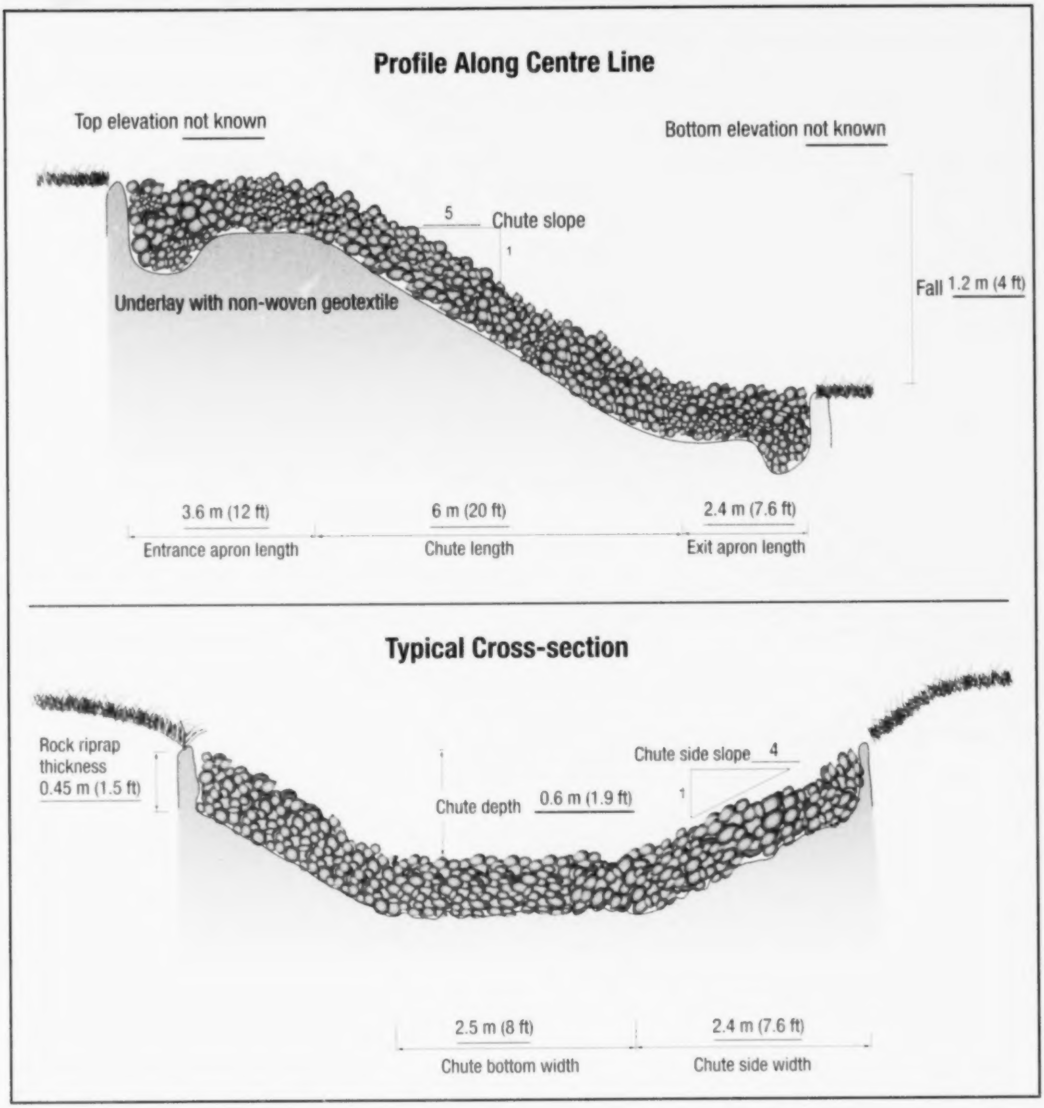


Figure 4.9. Rock Chute – Example Problem #1

Rock Chute – Example Problem #2

Determine the dimensions for a rock chute needed to safely convey the flows into an open ditch from the Determine Peak Flow Rate from an Agricultural Watershed – Example Problem #2 and the Grassed Waterway Example Problem #2. There are no space limitations and the fall into the ditch is 1.5 m (5 ft).

- design flow (Q) = 1.4 m^3/s (49 ft^3/s)
- grade to fit = 16.7% or 6:1 since there are no space limitations
- grassed waterway enters the top of the structure with a width of 11 m (36 ft) and a depth of 0.53 m (1.7 ft). The rock chute exits into the head of an open ditch. The ditch has a 2 m (6.6 ft) bottom width with 4:1 side slopes.

Solution

1. Use Table 4.14-M (4.14-I) as it uses the same grade to fit.
2. Find the necessary flow rate (Q) in the left hand column. At a flow rate of 1.4 m^3/s (49 ft^3/s), choose 2:1, 3:1 or 4:1 side slopes. Since the rock chute is to serve as a transition from a grassed waterway to an open ditch, consider the 4:1 side slope to best meet the change in dimensions.
3. Choose from a bottom width from 1-2.5 m (3-8 ft) wide. To best meet the 2 m (6.6 ft) wide bottom width of the ditch, use a 1.8 m (6 ft) bottom width.
4. Find the chute depth (D), where the flow rate (Q) = 1.4 m^3/s (49 ft^3/s) intersects the column showing side slope 4:1, bottom width 1.8 m (6 ft). In this case the depth is 0.6 m (2 ft).
5. Determine the total width of the chute. Since a 4:1 side slope is used, the width of each side will be 4 x 0.6 = 2.4 m (7.6 ft). Since two sides and one bottom are required, the total width of the chute is 2 x 2.4 + 1.8 = 6.6 m (22 ft). This is still narrower than the grassed waterway of 11 m (36 ft), so have the entrance apron of the chute start at 11 m (36 ft) wide and end at 6.6 m (22 ft) wide. Conversely, the same must happen at the exit apron of the chute.
6. Determine the length of the entrance apron by the greater of three times the fall or 3 m (10 ft). Since three times the fall is 3 x 1.5 = 4.5 m (15 ft), the entrance apron length is 4.5 m (15 ft).
7. Determine the horizontal length of the actual chute by multiplying the chosen chute slope by the fall at 6 x 1.5 = 9 m (30 ft).
8. Make the length of the exit apron twice the fall at 2 x 1.5 = 3 m (10 ft).
9. Determine the total length of the chute by adding the lengths of the three components together. For this example it works out to 16.5 m (55 ft).
10. Work out the amount of rock to order. The overall chute is 6.6 m (22 ft) wide and 16.5 m (55 ft) long, creating a horizontal surface area of 109 m^2 (1,210 ft^2). A further complication is that the chute is not all in a horizontal plane, so allow for a 5% increase in area when ordering the rock. This works out to 114 m^2 (1,271 ft^2). From before, the rock is to be 0.45 m (1.5 ft) deep. The chute volume rock required is 114 x 0.45 = 51.3 m^3 (1,271 x 1.5 = 1,907 ft^3 or 70.6 yd^3). Addition of the transition rock of 7.6 m^3 (10 yd^3) gives a total of 58.9 m^3 (80.6 yd^3) to order.
11. Enter this information on Figure 4.10.

Rock Chute Design Information Sheet – Example Problem #2

1. Watershed area	87.5 ha	216 ac
2. Average grade of watershed		1.58%
3. Runoff curve number from Tables 2.2 – 2.4		75
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)	1.4 m^3/s	49 ft^3/s
5. Rock chute fall	1.5 m	5 ft
6. Horizontal distance to obtain chute fall	9 m	30 ft
7. Grade to fit = $\frac{(5)}{(6)} \times 100$	$\frac{1.5\ m}{9\ m} \times 100$	$\frac{5\ ft}{30\ ft} \times 100$		16.7%
8. Type and size of input device	Waterway – 11 m (36 ft) wide	
9. Type and size of output device	Ditch – 14 m (46.6 ft) top width 2 m (6.6 ft) bottom width	
10. Chute slope from Tables 4.12-M to 4.14-M (4.12-I to 4.14-I)	6:1 or 16.7%	
11. Side slope		4:1
12. Bottom width	1.8 m	6 ft
13. Chute depth	0.6 m	2 ft
14. Chute width	6.6 m	22 ft
15. Total chute length	16.5 m	55 ft
16. Rock riprap to order for chute	51.3 m^3	70.6 yd^3
17. Additional rock riprap to order for transitions, curves, etc.	7.6 m^3	10 yd^3
18. Total rock riprap to order (16) + (17)	58.9 m^3	80.6 yd^3

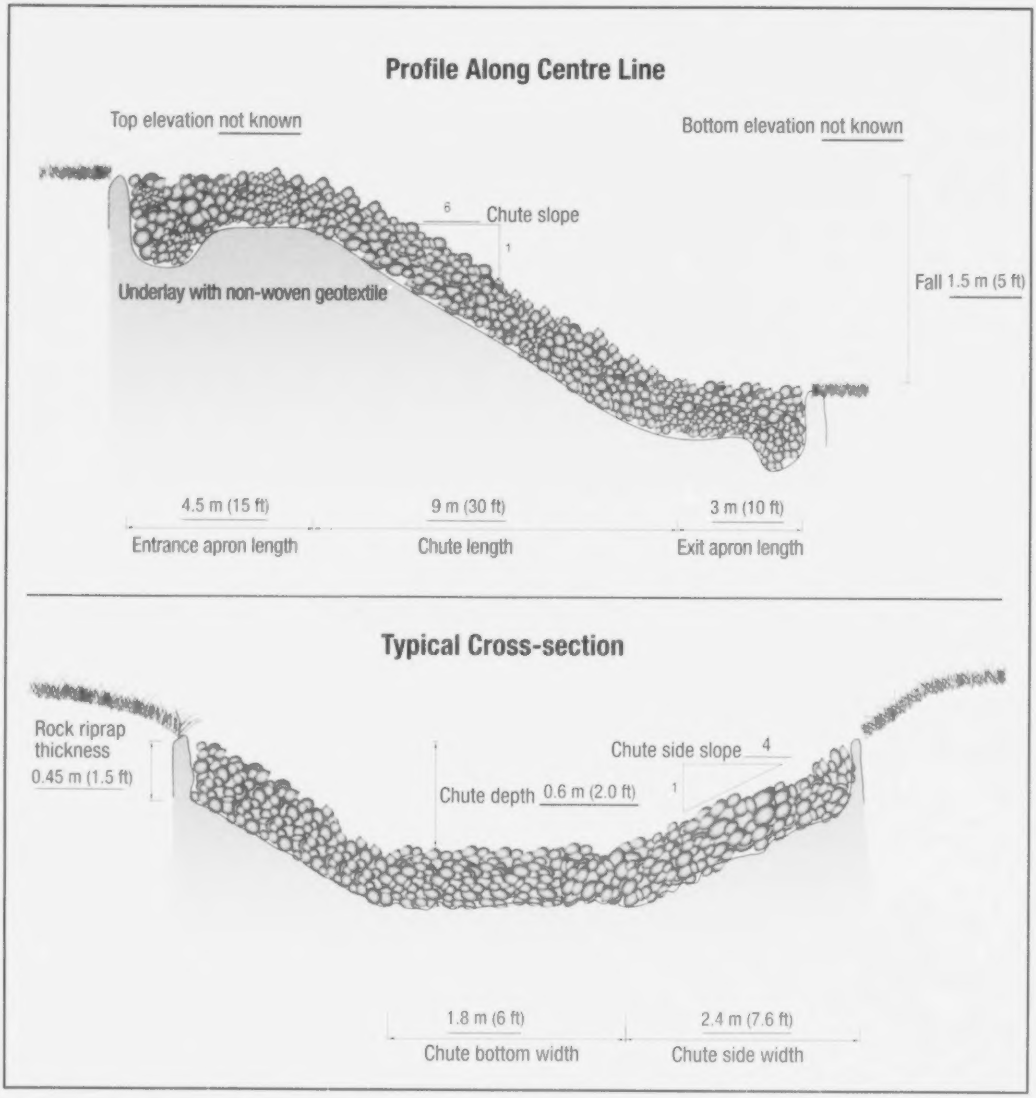


Figure 4.10. Rock Chute – Example Problem #2

Other Materials Used in Chute Spillways

Although rock riprap is primarily used in chute spillways, other materials can be used. These include poured concrete, gabion baskets or mats, interlocking blocks or timber structures. The design of a poured concrete structure is quite complex as concrete is not porous and requires the water pressure from underneath to be dissipated. Most poured concrete structures also have little ability to flex with base changes or frost heaving. This quality makes them very vulnerable to extensive damage if not properly designed and constructed.

Interlocking blocks, gabion baskets and mats can be easily and safely used in farm erosion control structures. The design principles are approximately the same as for rock chutes and manufacturers may also have their own design criteria.

4.3.2 Drop Pipe Inlets

Drop pipe inlets carry a concentrated flow of water through an enclosed pipe structure. Plastic, steel or concrete are commonly used materials. Drop pipe inlets are often located at the side of a large streambank or open ditch.

Conditions Where Applicable

The drop pipe inlet is the only erosion control device that can practically be used when a drop is greater than 1.5 m (5 ft) and the slope is over 20%. The drop pipe inlet system also has excellent potential as a component of a water storage system.

Flow Range

The following charts – Tables 4.15-M to 4.17-M (4.15-I to 4.17-I) – give a flow range up to 0.42 m^3/s (15 ft^3/s). If a higher flow rate is required, install several units parallel to each other.

Vertical Drop Range

This manual provides drop pipe inlet design for structures with 3 m (10 ft) or less fall. Once the drop exceeds 3 m (10 ft), the installation of a conventional drop pipe as shown in Figure 4.11 will become difficult and dangerous since a very deep trench must be excavated. A drop inlet called a high-drop inlet is designed for this purpose – use an experienced engineer for this kind of work.

Advantages of a Drop Pipe Inlet

- Once water is in the structure, it's totally contained. The structure doesn't rely on local soil conditions for erosion resistance, so the design can remain similar for most conditions.
- The unit can be prefabricated, reducing on-site construction time.
- The unit has a limit to capacity, making it suitable for water storage systems.

Disadvantages of a Drop Pipe Inlet

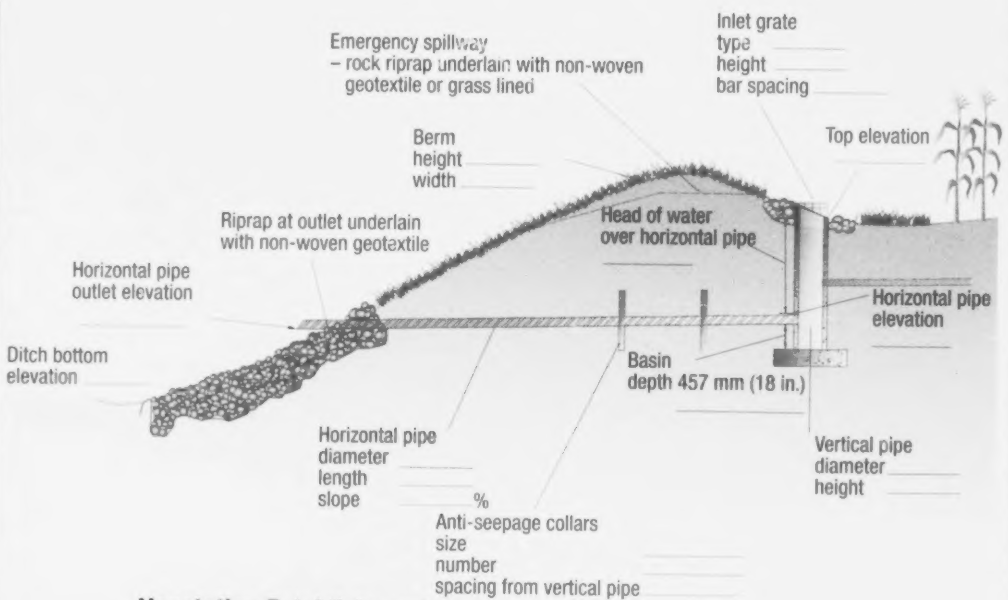
- The entry point of the spillway normally concentrates the water flow to a small area that's very vulnerable to erosion.
- A proper design is required to prevent the water from channeling along the sides of the pipe.
- The inlet has a limit to capacity. Once the capacity is reached, another control system is required to store the water or handle the excess flow.

Types of Drop Pipe Inlets

Drop Pipe Structure – The two components in this structure are a vertical pipe and a horizontal pipe (Figure 4.11). The drop pipe can be square or round in cross-section, and constructed of concrete, steel or plastic. Limited flow factors are the flow over the crest of the vertical pipe and the capacity of the horizontal pipe. These structures often require working in trenches. Proceed with caution and follow recommended safety procedures when working in trenches.

Sloped Pipe Structure – This structure consists of a sloped pipe (Figure 4.12). Capacity is normally determined by the length and internal roughness of the pipe. Slope of the pipe has very little effect since the "critical slope" (slope at which flow capacity doesn't increase with increase in slope) is exceeded under most circumstances. With the inlet type shown in Figure 4.12, the capacity of the system is similar to a horizontal pipe structure.

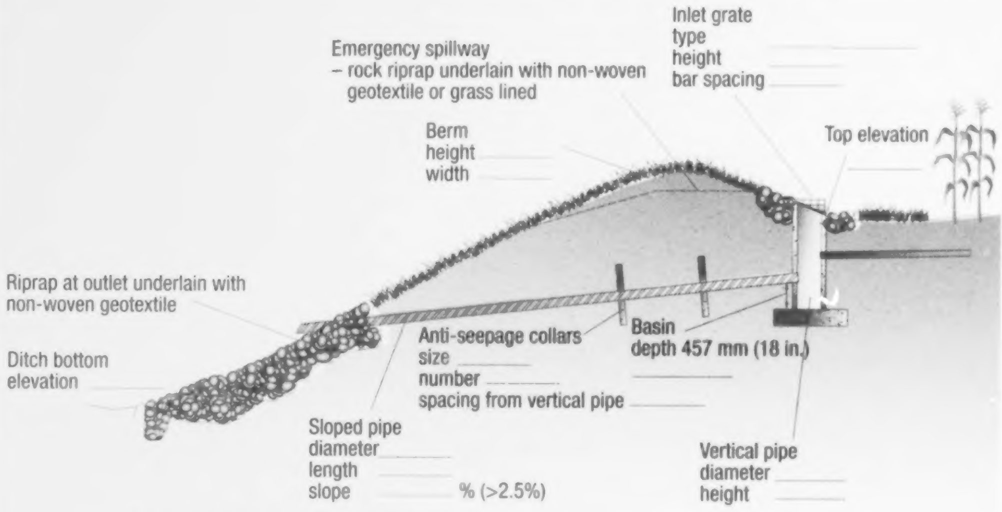
Small Capacity Riser Pipe – Another type of drop pipe is available to outlet into smaller diameter drain pipes (Figure 4.13). These inlets are commonly used in water and sediment control basin (WASCoB) systems as described in Section 4.5. Commercial companies produce several different models of this riser pipe, some are in Appendix D.



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.11. Drop Pipe Structure



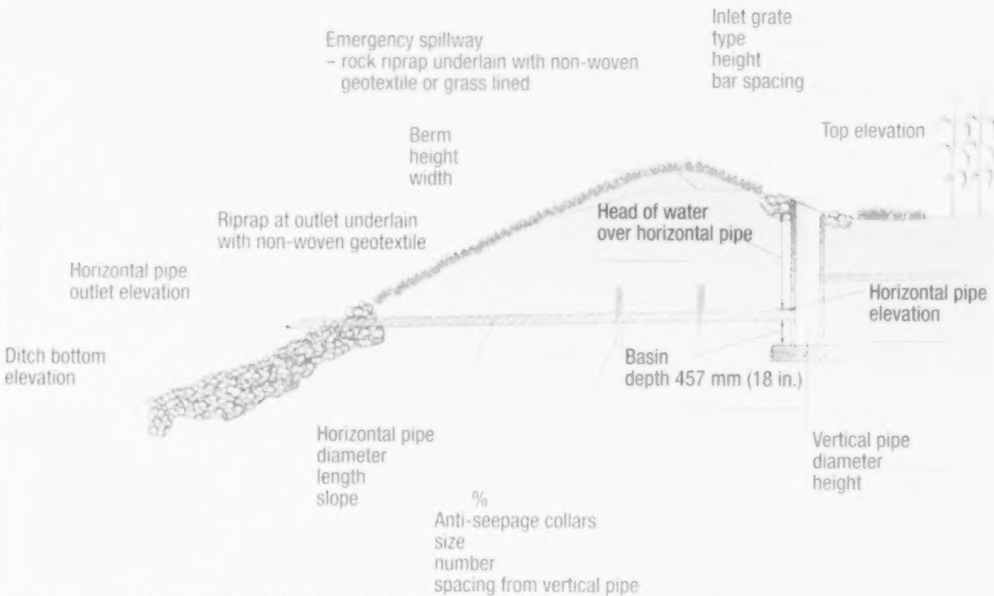
Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.12. Sloped Pipe Structure

Sloped Pipe Structure – This structure consists of a sloped pipe (Figure 4.12). Capacity is normally determined by the length and internal roughness of the pipe. Slope of the pipe has very little effect since the "critical slope" (slope at which flow capacity doesn't increase with increase in slope) is exceeded under most circumstances. With the inlet type shown in Figure 4.12, the capacity of the system is similar to a horizontal pipe structure.

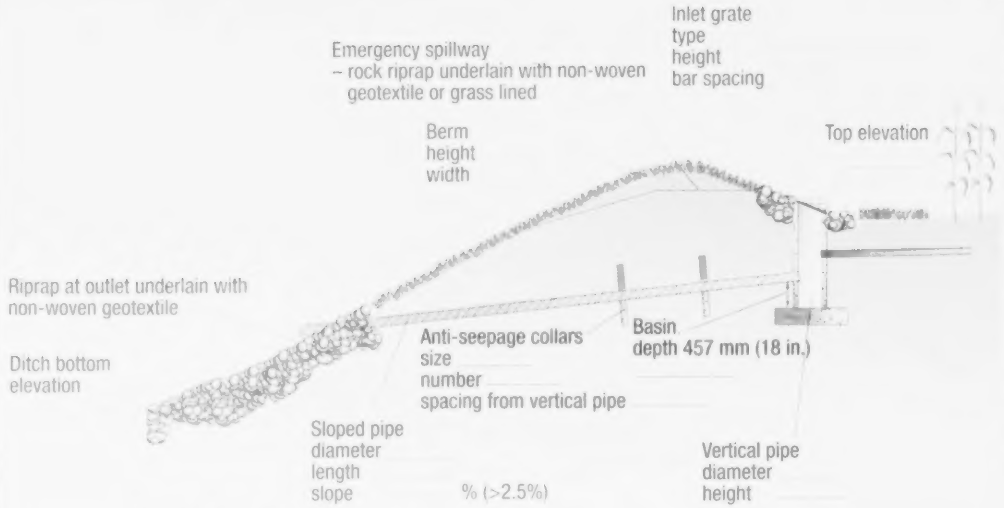
Small Capacity Riser Pipe – Another type of drop pipe is available to outlet into smaller diameter drain pipes (Figure 4.13). These inlets are commonly used in water and sediment control basin (WASCoB) systems as described in Section 4.5. Commercial companies produce several different models of this riser pipe, some are in Appendix D.



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

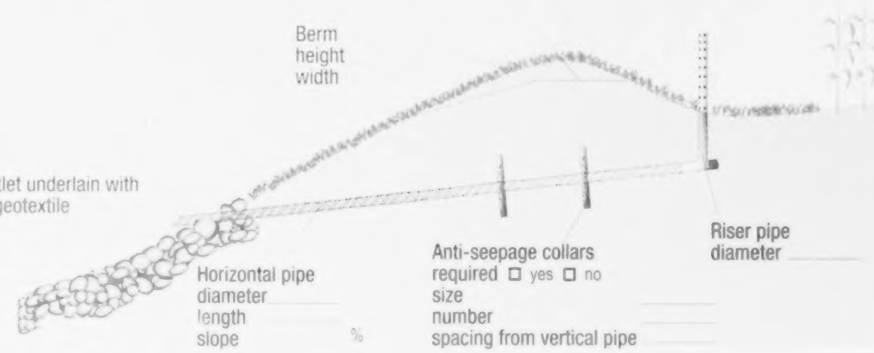
Figure 4.11: Drop Pipe Structure



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

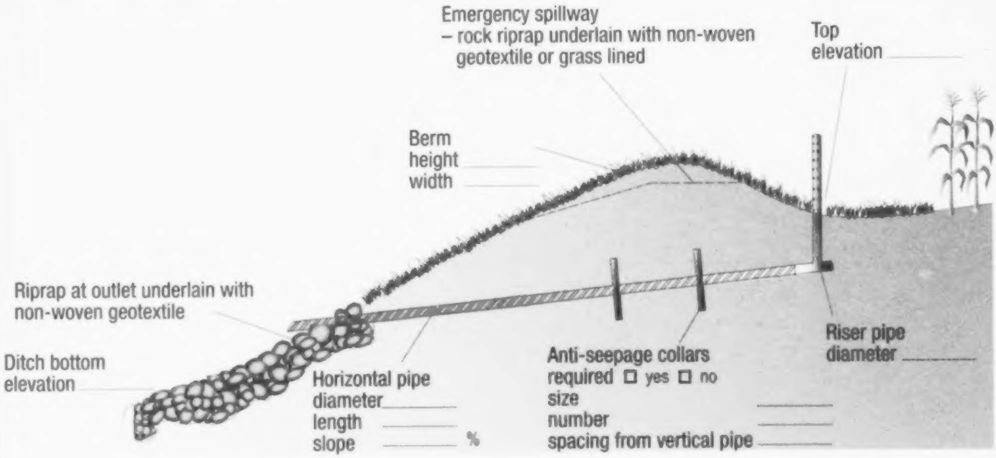
Figure 4.18 Sloped Pipe Structure



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.13. Small Capacity Riser Pipe Structure



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.13. Small Capacity Riser Pipe Structure

Design

To design a drop inlet spillway complete the following steps:

1. Estimate the peak flow of water entering the structure (see Section 2.3).
2. Determine the fall and horizontal distance where the drop structure will be installed.
3. Determine the type and size of structure required. Tables 4.15-M to 4.22-M (4.15-I to 4.22-I) show the capacities of several types and sizes of structures. The example gives a detailed explanation for using the tables. Choose a shorter vertical pipe and place more slope on the horizontal pipe to avoid digging a deep trench to accommodate the installation of a long vertical pipe.
4. Determine the height and length of the berm. The height is dependent on the head or stage of water needed to obtain the required flow of the spillway structure or the maximum height of water storage. For the design specifications given in Table 4.15-M to 4.16-M (4.15-I to 4.16-I), use a berm height of 0.45 m (18 in.). Add an additional 0.30 m (12 in.) of height for the drop pipe structure and the sloped pipe structure to allow for freeboard and settlement or shifting of the berm. For the small capacity riser pipe, ensure the freeboard is 10% of berm height to a maximum of 0.15 m (6 in.). For more information on the design and construction of berms, see Section 4.5, Water and Sediment Control Basins.
5. Incorporate an emergency spillway into the design, to at least protect the crest of the berm. For design of the spillway see Section 4.5, Water and Sediment Control Basins.
6. Protection may be necessary at the outlet of the pipe. This protection often consists of rock riprap underlain by non-woven geotextile.
7. Complete the layout of the structure, berm, slopes, inlet, etc. Consider possible problems with water tracking along the outside of the pipe. Anti-seepage collars are often installed to increase resistance to external water flow. See design information on anti-seepage collars later in this section for more information.

   Another very important feature is the design of the inlet grate. If the inlet is connected to a large underground drainage system, keep the grate spacing small enough to prevent animal entry and prevent large debris from plugging the outlet pipe. OMAFRA Publication 29, *Drainage Guide for Ontario*, recommends that the outlet pipes have grate openings not greater than 25 mm (1 in.).

   On systems with short, larger diameter horizontal pipes, an outlet grate is normally not recommended. The quick flow of water is assumed to flush any animals or debris out of the system. On these systems, the inlet grate only prevents entry of humans or very large debris. Grate spacing is suggested to be 30% to 50% of the horizontal pipe diameter. Ensure the inlet is visible and prevents accidental human entry. A riser type of inlet is normally recommended as it increases the overall filter area.

   When discharging the pipe to a safe outlet, slope the pipe approximately 1% (or more) to ensure good drainage.
8. Incorporate the spillway with other erosion works. Control erosion above and below the spillway to prevent the failure of the spillway.

Table 4.15-M. Design of a Drop Pipe Structure – Horizontal Pipe Diameter Required (mm)

	Head of Water Over Horizontal Pipe			
Capacity (m^3/s)	0.60 m	1.20 m	1.80 m	2.45 m
0.07	375 mm	300 mm	300 mm	300 mm
0.14	375 mm	375 mm	375 mm	375 mm
0.21	450 mm	450 mm	375 mm	375 mm
0.28	535 mm	450 mm	450 mm	375 mm
0.35	535 mm	535 mm	450 mm	450 mm
0.42	600 mm	535 mm	535 mm	450 mm

Table 4.15-I. Design of a Drop Pipe Structure – Horizontal Pipe Diameter Required (in.)

	Head of Water Over Horizontal Pipe			
Capacity (ft^3/s)	2 ft	4 ft	6 ft	8 ft
2.5	15 in.	12 in.	12 in.	12 in.
5.0	15 in.	15 in.	15 in.	15 in.
7.5	18 in.	18 in.	15 in.	15 in.
10.0	21 in.	18 in.	18 in.	15 in.
12.5	21 in.	21 in.	18 in.	18 in.
15.0	24 in.	21 in.	21 in.	18 in.

Table 4.16-M. Design of a Drop Pipe Structure – Vertical Pipe Diameter Required (mm)

Horizontal Pipe Diameter	Vertical Pipe Diameter
300 mm	535 mm
375 mm	600 mm
450 mm	600 mm
535 mm	760 mm
600 mm	915 mm

Table 4.16-I. Design of a Drop Pipe Structure – Vertical Pipe Diameter Required (in.)

Horizontal Pipe Diameter	Vertical Pipe Diameter
12 in.	21 in.
15 in.	24 in.
18 in.	24 in.
21 in.	30 in.
24 in.	36 in.

Assumptions used in above charts:
- corrugated metal is used
- horizontal pipe is 18 m (60 ft) long -- shorter pipes have great capacity and longer pipes have less capacity
- minimum of 450 mm (18 in.) of water height allowed over vertical pipe
- free outlet

Table 4.17-M. Design of a Sloped Pipe Structure

Maximum Capacity (m^3/s)	Sloped Pipe Diameter Required
0.026	200 mm
0.045	250 mm
0.074	300 mm
0.130	375 mm
0.201	450 mm
0.312	535 mm
0.425	600 mm

Table 4.17-I. Design of a Sloped Pipe Structure

Maximum Capacity (ft^3/s)	Sloped Pipe Diameter Required
0.9	8 in.
1.6	10 in.
2.6	12 in.
4.6	15 in.
7.1	18 in.
11.0	21 in.
15.0	24 in.

Source: Adapted from ARMCO Handbook of Drainage, 1955

Assumptions used in above charts:
- corrugated metal is used
- water surface at inlet is at same elevation as top of pipe
- outlet is not submerged
- slope is at least 2.5%

Table 4.18-M. Design of Small Capacity Riser Pipes – Horizontal Pipe Diameter Required (mm)

Capacity (m^3/s)	Slope of Horizontal Pipe					
	0.5%	0.75%	1.0%	1.5%	2.0%	3.0%
0.007	150 mm	150 mm	150 mm	150 mm	150 mm	100 mm
0.014	200 mm	200 mm	200 mm	200 mm	150 mm	150 mm
0.021	250 mm	250 mm	200 mm	200 mm	200 mm	200 mm
0.028	250 mm	250 mm	250 mm	200 mm	200 mm	200 mm

Table 4.18-I. Design of Small Capacity Riser Pipes – Horizontal Pipe Diameter Required (in.)

Capacity (ft^3/s)	Slope of Horizontal Pipe					
	0.5%	0.75%	1.0%	1.5%	2.0%	3.0%
0.25	6 in.	6 in.	6 in.	6 in.	6 in.	4 in.
0.5	8 in.	8 in.	8 in.	8 in.	6 in.	6 in.
0.75	10 in.	10 in.	8 in.	8 in.	8 in.	8 in.
1.0	10 in.	10 in.	10 in.	8 in.	8 in.	8 in.

Assumptions used in above charts:
- plastic tile
- free outlet

Table 4.19-M. Small Capacity Riser Pipe Flowrates (full flow)*, 150 mm diameter riser pipe

Depth of Water (m)	Flowrate (m^3/s)
0.30	0.020
0.61	0.043
0.91	0.057

Table 4.19-I. Small Capacity Riser Pipe Flowrates (full flow)*, 6 in. diameter riser pipe

Depth of Water (m)	Flowrate (ft^3/s)
1	0.71
2	1.51
3	2.00

Table 4.20-M. Small Capacity Riser Pipe Flowrates (full flow)*, 200 mm diameter riser pipe

Depth of Water (m)	Flowrate (m^3/s)
0.30	0.027
0.61	0.065
0.91	0.095

Table 4.20-I. Small Capacity Riser Pipe Flowrates (full flow)*, 8 in. diameter riser pipe

Depth of Water (m)	Flowrate (ft^3/s)
1	0.95
2	2.30
3	3.34

Table 4.21-M. Small Capacity Riser Pipe Flowrates Using Orifice Openings*, 150 mm diameter riser pipe

Depth of Water (m)	Flowrate (m^3/s) with 68 mm Diameter Orifice Openings	Flowrate (m^3/s) with 93 mm Diameter Orifice Openings
0.30	0.011	0.016
0.61	0.014	0.025
0.91	0.016	0.029

Table 4.21-I. Small Capacity Riser Pipe Flowrates Using Orifice Openings*, 6 in. diameter riser pipe

Depth of Water (ft)	Flowrate (ft^3/s) with 2.67 in. Diameter Orifice Openings	Flowrate (ft^3/s) with 3.67 in. Diameter Orifice Openings
1	0.39	0.58
2	0.51	0.89
3	0.58	1.03

*Flowrate values obtained from University of Guelph test results on 1986 style 'Hickenbottom' units. Depth of water is depth of ponded water above ground level at riser pipe location. Orifice plate is to be located 400 mm (16 in.) below ground surface. Use 50% of full flow rates above for 150-200 mm (6-8 in.) riser pipes when plugging of openings may be a problem.

Table 4.22-M. Small Capacity Riser Pipe Flowrates using Orifice Openings*, 200 mm diameter riser pipe

Depth of Water (m)	Flowrate (m^3/s) with 102 mm Diameter Orifice Openings	Flowrate (m^3/s) with 127 mm Diameter Orifice Openings	Flowrate (m^3/s) with 152 mm Diameter Orifice Openings	Flowrate (m^3/s) with 178 mm Diameter Orifice Openings
0.30	0.014	0.017	0.018	0.022
0.61	0.030	0.046	0.061	0.068
0.91	0.036	0.060	0.084	0.095

Table 4.22-I. Small Capacity Riser Pipe Flowrates Using Orifice Openings*, 8 in. diameter riser pipe

Depth of Water (ft)	Flowrate (m^3/s) 4.0 in. Diameter Orifice Openings	Flowrate (m^3/s) with 5.0 in. Diameter Orifice Openings	Flowrate (m^3/s) with 6.0 in. Diameter Orifice Openings	Flowrate (m^3/s) with 7.0 in. Diameter Orifice Openings
1	0.5	0.61	0.64	0.78
2	1.07	1.64	2.16	2.39
3	1.27	2.11	2.97	3.34

*Flowrate values obtained from University of Guelph test results on 1986 style 'Hickenbottom' units. Depth of water is depth of ponded water above ground level at riser pipe location. Orifice plate is to be located 400 mm (16 in.) below ground surface. Use 50% of full flow rates above for 150-200 mm (6-8 in.) riser pipes when plugging of openings may be a problem.

Design Information on Anti-seepage Collars

When Are Collars Used?

- collars are required on all drop pipe inlets except small capacity riser pipe structures and structures with horizontal pipes longer than 30 m (100 ft) (see Section 4.3.2)

How Many Collars are Required?

- use one collar on all structures with horizontal pipes less than 300 mm (12 in.) in diameter
- use one collar on structures with horizontal pipes 300 mm (12 in.) or greater in diameter and less than 5 m (16 ft) long
- use two collars on structures with horizontal pipes 300 mm (12 in.) or greater in diameter and longer than 5 m (16 ft)

Minimum Size of Collars Required

- make the diameter or minimum size dimension of a collar three times the diameter of the horizontal pipe

Collar Location

- always place on the horizontal pipe
- place first collar 1.5 m (5 ft) from drop pipe or inlet of the sloped pipe structure
- place the second collar, if necessary, 3.7 m (12 ft) from first collar or 5.2 m (17 ft) from drop pipe or inlet of the sloped pipe structure

Collar Installation

- use plastic, steel or pressure treated wood as a material
- make sure the space between pipe and collar is well sealed
- tamp down earth around collar

Installation Procedures

The installation method will vary with the size of structure, the height of drop and the type of erosion control system above or below, but the following procedures are constant throughout.

- Remove all debris in the vicinity of the structure.
- Determine where the drop pipe inlet is to be placed. On a large gully control project this is often a matter of economics. Landowners often want to reclaim the complete gully. But the cost of fill may greatly exceed the value of the land reclaimed. Locate the inlet where it will cause the least disruption to working the fields. A measurement of machinery size may be necessary.
- Formulate the sequence of construction. Structures that are hard to modify are usually installed first. For example, install the vertical pipe before the construction of the upper approach waterway is complete. The final grade of the waterway can easily blend into the inlet of the vertical pipe.
- Prevent or control differential settlement. It's usually necessary to completely remove any brush or roots. Widen out the pipe trench to prevent a cavity from occurring under the compacted berm (see Figure 4.14). Add additional fill to areas with deeper fill to allow for the extra settlement.

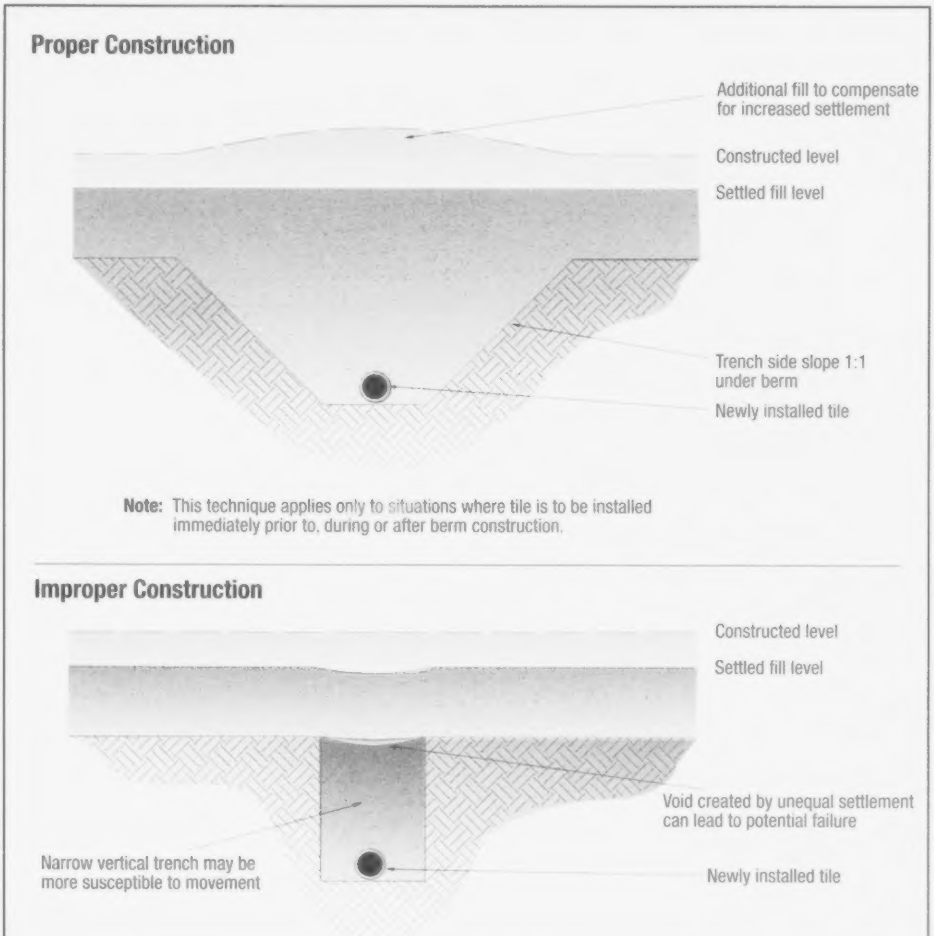


Figure 4.14. Differential Settlement of a Berm

Maintenance

- When subjected to heavy trash conditions, no surface inlet can totally avert plugging problems. Remove obstructions in the inlet grate or spillway prior to runoff events. If these obstructions seem to be excessive, install a different inlet system.
- Swirling around the inlet may cause severe erosion scour which can lead to structural failure. Control swirling by installing an anti-vortex or baffle plate positioned across the top of the inlet.
- Watch for cracks in the berm or spillway foundation. If cracks occur, repair them immediately. The angle of the backslope will often have to be decreased to prevent further failure.
- Dig a path through snow or ice to the inlet just before the peak flow is expected.
- Watch for movement of water along the outside of the pipe. If this occurs, the water will either enter the pipe further down or it will track outside the pipe all the way. If this isn't stopped, this situation will eventually cause a failure. Fully seal the pipe or install anti-seepage collars to remedy the situation.
- Control vegetative growth around the surface inlet so it doesn't hamper inlet performance.

Drop Pipe Inlet Design Information Sheet

1. Watershed area	_____ ha	_____ ac
2. Average grade of watershed		_____ %
3. Runoff curve number from Tables 2.2 – 2.4		_____
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)	_____ m^3/s	_____ ft^3/s
5. Drop pipe fall (top elevation – bottom elevation)	_____ m	_____ ft
6. Horizontal distance to complete fall	_____ m	_____ ft
7. Type of drop pipe inlet – Section 4.3.2. Fill out applicable section below (A/B/C)		

A. Drop pipe structure

Number of units		
Head of water over horizontal pipe	_____ m	_____ ft
Horizontal pipe diameter – Table 4.15-M (4.15-I)	_____ mm	_____ in.
Vertical pipe diameter – Table 4.16-M (4.16-I)	_____ mm	_____ in.
Berm height (min. 450 mm (18 in.) + freeboard 300 mm (12 in.))	_____ mm	_____ in.

B. Sloped pipe structure

Number of units		
Slope of pipe (>2.5%) $\frac{\text{m (} \quad \text{ft) fall}}{\text{m (} \quad \text{ft) length}}$ x 100 = _____ %		_____ %
Diameter of sloped pipe – Table 4.17-M (4.17-I)	_____ mm	_____ in.
Berm height (pipe diameter + freeboard 300 mm (12 in.))	_____ mm	_____ in.

C. Small capacity riser pipe

Number of units			
Slope of horizontal pipe			_____ %
Diameter of horizontal pipe – Table 4.18-M (4.18-I)		_____ mm	_____ in.
Riser pipe diameter – Table 4.19-M to 4.20-M (4.19-I to 4.20-I)		_____ mm	_____ in.
Orifice plate required – Table 4.21-M to 4.22-M (4.21-I to 4.22-I)	❑ No ❑ Yes	diameter _____ mm	diameter _____ in.
Berm height (depth of water + freeboard (minimum 0.15 m (6 in.)))		_____ mm	_____ in.

8. Anti-seepage collars required – Section 4.3.2	❑ No ❑ Yes			
Number of collars	_____			
Diameter required	_____ mm		_____ in.	
Distance from drop pipe	1st collar		2nd collar	
	_____ m	_____ ft	_____ m	_____ ft
9. Inlet grate – spacing of bars (refer to Section 4.3.2)	_____ mm		_____ in.	
10. Horizontal or sloped pipe – length	_____ m		_____ ft	

11. Enter other dimensions on sketches (Figures 4.11 – 4.13).

Drop Pipe Inlet – Example Problem #1 (Drop Pipe Structure)

Design a drop pipe inlet for a gully control system that meets the following requirements:

- design flow Q = 0.28 m^3/s (10 ft^3/s)
- drop = 3.0 m (10 ft)
- peak flow from watershed (10-year storm) = 0.28 m^3/s (10 ft^3/s)
- horizontal distance to drop = 15 m (50 ft)
- farmer doesn't want to reclaim gully

Procedure

1. Determine what type of drop pipe inlet to use. A drop pipe structure is proposed.
2. Refer to Table 4.15-M (4.15-I). With a flow of 0.28 m^3/s (10 ft^3/s), and for ease and safety of installation, use a 2.1 m (6.9 ft) head of water over the horizontal pipe. A horizontal pipe of 450 mm (18 in.) in diameter is required.
3. Refer to Table 4.16-M (4.16-I) to determine that a vertical pipe 600 mm (24 in.) in diameter is required.
4. Table 4.16-M (4.16-I) footnotes specify that the berm must pond water at least 450 mm (18 in.) high to provide the water height to the emergency spillway. Make the berm approximately another 300 mm (12 in.) higher to make sure the extra water runs through the spillway. The 300 mm (12 in.) will also give an allowance for settlement.
5. Specify the number and size of anti-seepage collars required. See previous section for design. For this example, two 1,350 mm (54 in.) diameter anti-seepage collars are required.
6. Determine the bank slope required. For this example, there was adequate length to give a 5:1 slope. A slope seeding of trefoil-fescue was chosen to give a short competitive growth.
7. The length of the horizontal pipe can be calculated or estimated. For this example a 15 m (50 ft) length was estimated. The slope of the horizontal pipe is 2%.

See Figure 4.15 for a completed example.

Drop Pipe Inlet Design Information Sheet – Example Problem #1 (Drop Pipe Structure)

1. Watershed area	N/A	N/A
2. Average grade of watershed	N/A	
3. Runoff curve number from Tables 2.2 – 2.4	N/A	
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)	0.28 m^3/s	10 ft^3/s
5. Drop pipe fall (top elevation – bottom elevation)	3.0 m	10 ft
6. Horizontal distance to complete fall	15 m	50 ft
7. Type of drop pipe inlet – Section 4.3.2 Fill out applicable section below (A/B/C)	Drop pipe structure	

A. Drop pipe structure

Number of units	1	
Head of water over horizontal pipe	2.1 m (use 1.8 m)	6.9 ft (use 6 ft)
Horizontal pipe diameter – Table 4.15-M (4.15-I)	450 mm	18 in.
Vertical pipe diameter – Table 4.16-M (4.16-I)	600 mm	24 in.
Berm height (min. 450 mm (18 in.) + freeboard 300 mm (12 in.))	750 mm	30 in.

B. Sloped pipe structure

Number of units N/A		
Slope of pipe (>2.5%) $\frac{\text{m (} \quad \text{ft) fall}}{\text{m (} \quad \text{ft) length}}$ x 100 = ______ %		N/A
Diameter of sloped pipe – Table 4.17-M (4.17-I)	N/A	N/A
Berm height (pipe diameter + freeboard 300 mm (12 in.))	N/A	N/A

C. Small capacity riser pipe

Number of units			N/A
Slope of horizontal pipe			N/A
Diameter of horizontal pipe – Table 4.18-M (4.18-I)		N/A	N/A
Riser pipe diameter – Table 4.19-M to 4.20-M (4.19-I to 4.20-I)		N/A	N/A
Orifice plate required – Table 4.21-M to 4.22-M (4.21-I to 4.22-I)	❑ No ❑ Yes	N/A	N/A
Berm height (depth of water + freeboard (minimum 0.15 m (6 in.)))		N/A	N/A

8. Anti-seepage collars

Anti-seepage collars required – Section 4.3.2	❑ No ☑ Yes			
Number of collars	2			
Diameter required	1,350 mm		54 in.	
Distance from drop pipe	1st collar		2nd collar	
	1.5 m	5 ft	5.2 m	17 ft

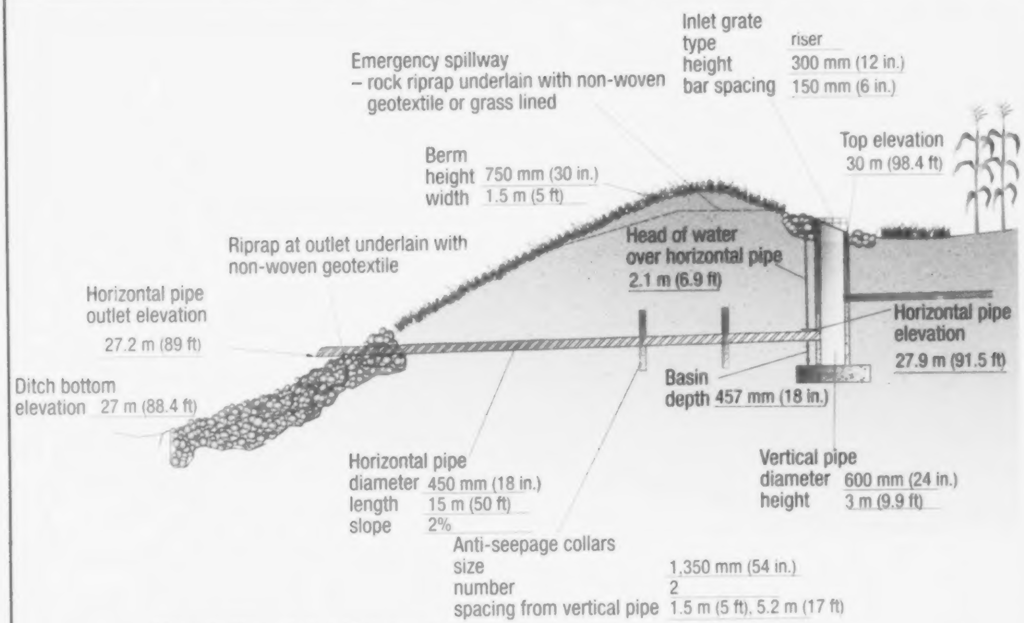
9. Inlet grate

Spacing of bars on inlet grate (refer to Section 4.3.2)	150 mm	6 in.

10. Horizontal or sloped pipe

Length of horizontal or sloped pipe	15 m	50 ft

11. Enter dimensions on sketch (Figures 4.15).



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.15. Drop Pipe Structure – Example Problem #1

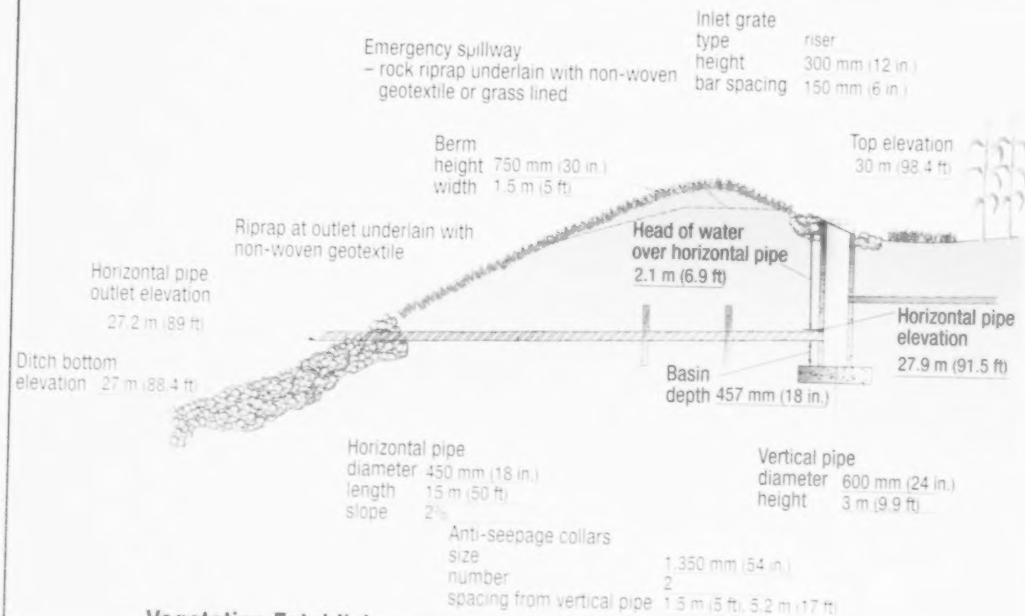
Drop Pipe Inlet – Example Problem #2 (Sloped Pipe Structure)

A farmer wants to control gully erosion along a watercourse on the farm. Design a drop pipe inlet for a gully control system that meets the following requirements:

- design flow Q = 0.13 m^3/s (4.6 ft^3/s)
- drop = 3 m (10 ft)
- horizontal distance to drop = 12 m (40 ft)
- farmer doesn't want to reclaim gully

Procedure

1. Determine what type of drop pipe inlet to use. A sloped pipe structure is proposed.
2. Refer to Table 4.17-M (4.17-I). With a flow of 0.13 m^3/s (4.6 ft^3/s), a sloped pipe diameter of 375 mm (15 in.) is required.
3. Assume a small diversion berm 0.45 m (1.5 ft) will be constructed along the watercourse to bring all runoff to this location.



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.15 Drop Pipe Structure – Example Problem #1

Drop Pipe Inlet – Example Problem #2 (Sloped Pipe Structure)

A farmer wants to control gully erosion along a watercourse on the farm. Design a drop pipe inlet for a gully control system that meets the following requirements:

- design flow Q = 0.13 m^3/s (4.6 ft^3/s)
- drop = 3 m (10 ft)
- horizontal distance to drop = 12 m (40 ft)
- farmer doesn't want to reclaim gully

Procedure

1. Determine what type of drop pipe inlet to use. A sloped pipe structure is proposed.
2. Refer to Table 4.17-M (4.17-I). With a flow of 0.13 m^3/s (4.6 ft^3/s), a sloped pipe diameter of 375 mm (15 in.) is required.
3. Assume a small diversion berm 0.45 m (1.5 ft) will be constructed along the watercourse to bring all runoff to this location.

4. A 0.6 m x 0.6 m x 1.2 m high (2 ft x 2 ft x 4 ft high) concrete catch basin with sloped top and birdcage grate is proposed as the inlet to the pipe.
5. Specify the number and size of anti-seepage collars required. For this example, two collars, sized three times the proposed pipe diameter are required, so use two 1,125 mm (45 in.) diameter anti-seepage collars.
6. Determine the bank slope required. For this example, the watercourse bank will be reclaimed at a 3:1 slope. A seeding of clover-fescue was chosen to give a short competitive growth.
7. The length of the sloped pipe can be calculated or estimated. For this example a 13 m (43 ft) length was estimated. The slope of the sloped pipe, before it reaches the watercourse, is set at 15%.

See Figure 4.16 for a completed example.

Drop Pipe Inlet Design Information Sheet – Example Problem #2 (Sloped Pipe Structure)

1. Watershed area	N/A	N/A
2. Average grade of watershed		N/A
3. Runoff curve number from Tables 2.2 – 2.4		N/A
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)	0.13 m^3/s	4.6 ft^3/s
5. Drop pipe fall (top elevation – bottom elevation)	2.7 m	9 ft
6. Horizontal distance to complete fall	12 m	40 ft
7. Type of drop pipe inlet – Section 4.3.2 Fill out applicable section below (A/B/C)		Sloped pipe structure

A. Drop pipe structure

Number of units		N/A
Head of water over horizontal pipe	N/A	N/A
Horizontal pipe diameter – Table 4.15-M (4.15-I)	N/A	N/A
Vertical pipe diameter – Table 4.16-M (4.16-I)	N/A	N/A
Berm height (min. 450 mm (18 in.) + freeboard 300 mm (12 in.))	N/A	N/A

B. Sloped pipe structure

Number of units		1
Slope of pipe (>2.5%) $\frac{\text{1.95 m (6.5 ft) fall}}{\text{13 m (43 ft) length}}$ x 100 = 15%		15%
Diameter of sloped pipe – Table 4.17-M (4.17-I)	375 mm	15 in.
Berm height (pipe diameter + freeboard 300 mm (12 in.))	675 mm	27 in.

C. Small capacity riser pipe

Number of units			N/A
Slope of horizontal pipe			N/A
Diameter of horizontal pipe – Table 4.18-M (4.18-I)		N/A	N/A
Riser pipe diameter – Table 4.19-M to 4.20-M (4.19-I to 4.20-I)		N/A	N/A
Orifice plate required – Table 4.21-M to 4.22-M (4.21-I to 4.22-I)	N/A	N/A	N/A
Berm height (depth of water + freeboard (minimum 0.15 m (6 in.)))		N/A	N/A

8. Anti-seepage collars

Anti-seepage collars required – Section 4.3.2	❑ No ☑ Yes			
Number of collars	2			
Diameter required	1,125 mm		45 in.	
Distance from drop pipe	1st collar		2nd collar	
	1.5 m	5 ft	5.2 mm	17 ft

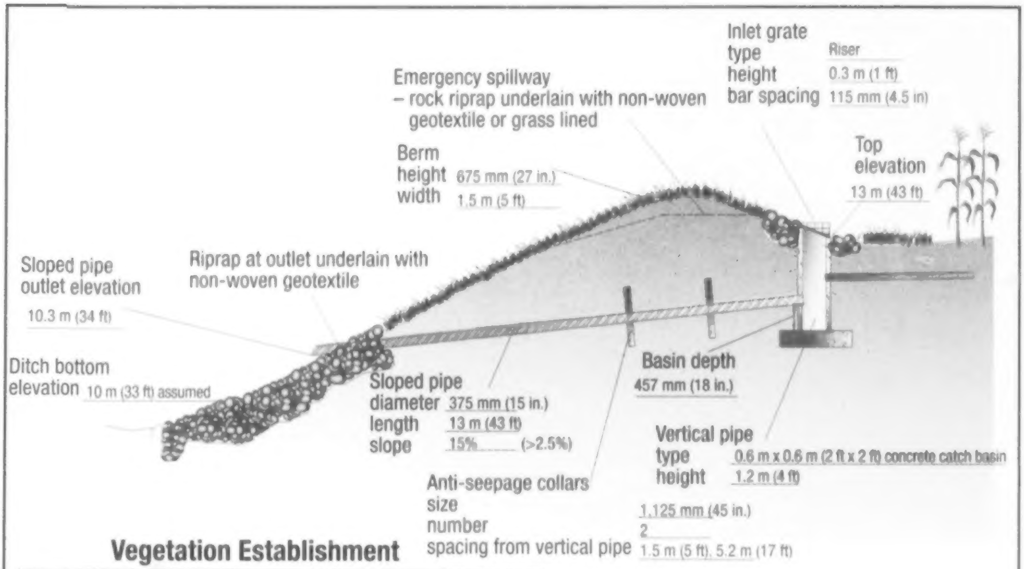
9. Inlet grate

Spacing of bars on inlet grate (refer to Section 4.3.2)	115 mm	4.5 in.

10. Horizontal or sloped pipe

Length of horizontal or sloped pipe	13 m	43 ft

11. Enter other dimensions on sketch (Figures 4.16).



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.16. Sloped Pipe Structure – Example Problem #2

4.3.3 Grade Control Structures

Use grade control structures to reduce waterway grades, and for small (up to 1 m (3 ft)) vertical drops at abrupt changes in grade. Agricultural uses include:

- drops along grassed waterways to create shallower and less erodible grades, including waterways having grades greater than 5%
- abrupt grade changes at lane crossings, edges of fields, or waterway exits into drainage ditches

Other uses might include sediment traps or grade control in drainage ditches, but would require a more detailed design.

Types

The two main types of grade control structures currently used in agriculture in Ontario are wood log and gabion basket (Figure 4.17).

Wood Log Type – This is a more temporary grade control structure as it will rot over time. Use pressure treated wood or cedar timber to prolong the life of this structure.

Gabion Basket Type – This is a much more permanent structure, although the wire baskets can deteriorate after several years. It's more costly than wood log types, especially if rock must be trucked a long distance.

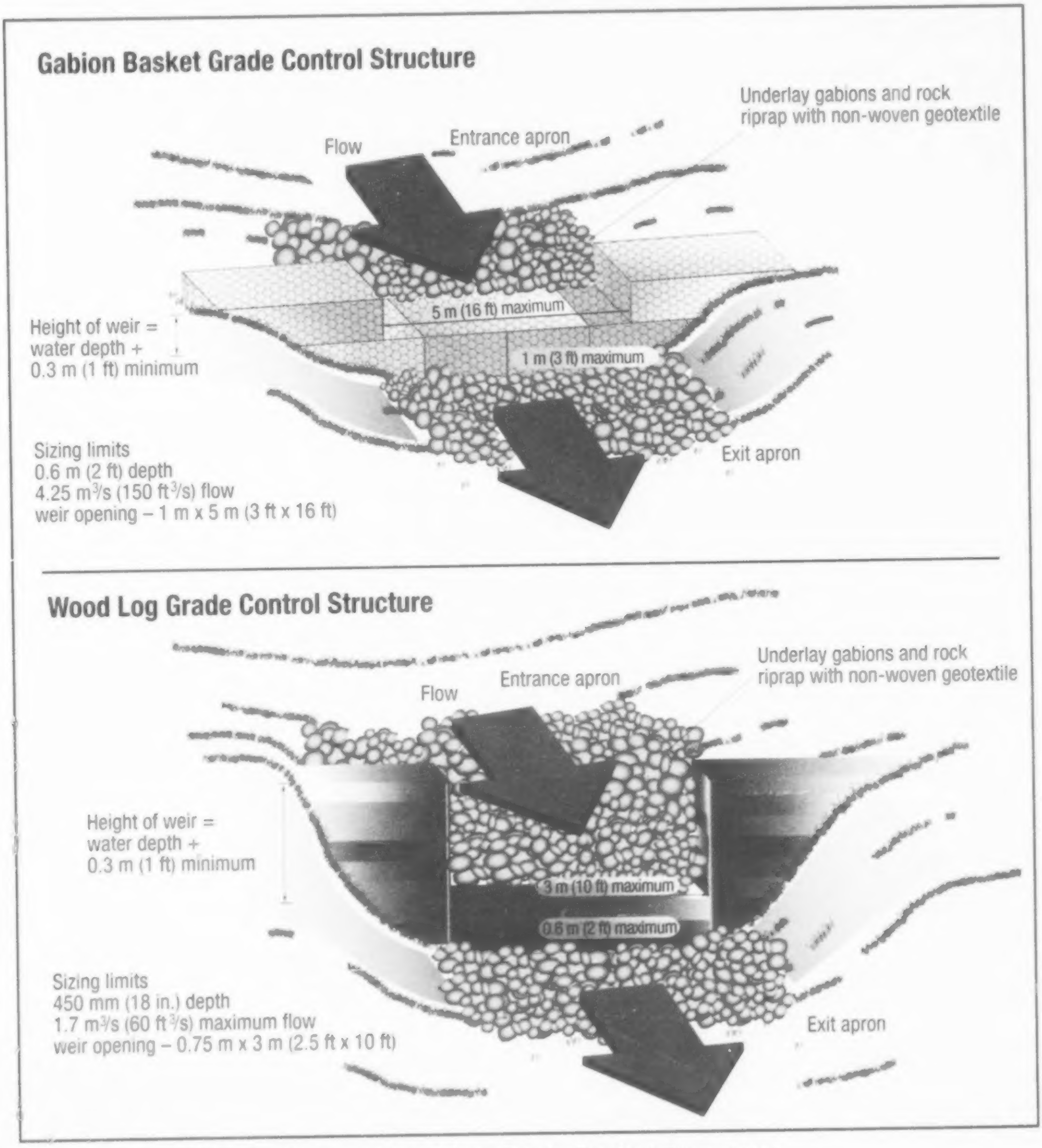
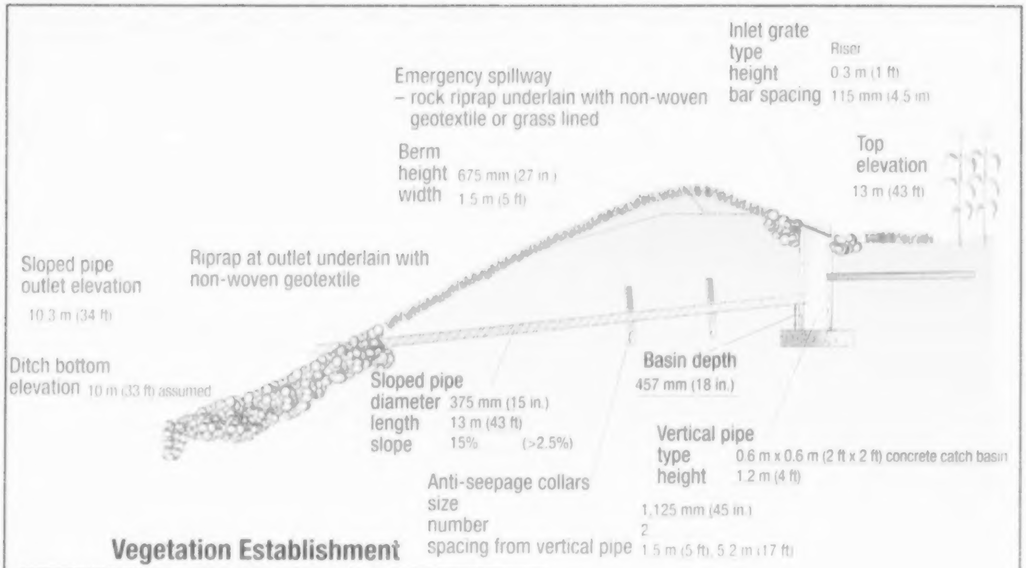


Figure 4.17. Gabion Basket and Wood Log Grade Control Structures



Vegetation Establishment

Vegetation	Rate
Permanent seed - creeping red fescue (50%) - perennial ryegrass (45%) - white clover (5%)	80 kg/ha (70 lb/ac)
Nurse crop - spring or fall grain	80 kg/ha (70 lb/ac)
Mulch with straw (crimped) - consider mulch blanket on steep, sensitive areas and where immediate erosion protection is necessary	1,000 kg/ha (900 lb/ac)

Figure 4.18. Sloped Pipe Structure – Example Problem #2

4.3.3 Grade Control Structures

Use grade control structures to reduce waterway grades, and for small (up to 1 m (3 ft)) vertical drops at abrupt changes in grade. Agricultural uses include:

- drops along grassed waterways to create shallower and less erodible grades, including waterways having grades greater than 5%
- abrupt grade changes at lane crossings, edges of fields, or waterway exits into drainage ditches

Other uses might include sediment traps or grade control in drainage ditches, but would require a more detailed design.

Types

The two main types of grade control structures currently used in agriculture in Ontario are wood log and gabion basket (Figure 4.17).

Wood Log Type – This is a more temporary grade control structure as it will rot over time. Use pressure treated wood or cedar timber to prolong the life of this structure.

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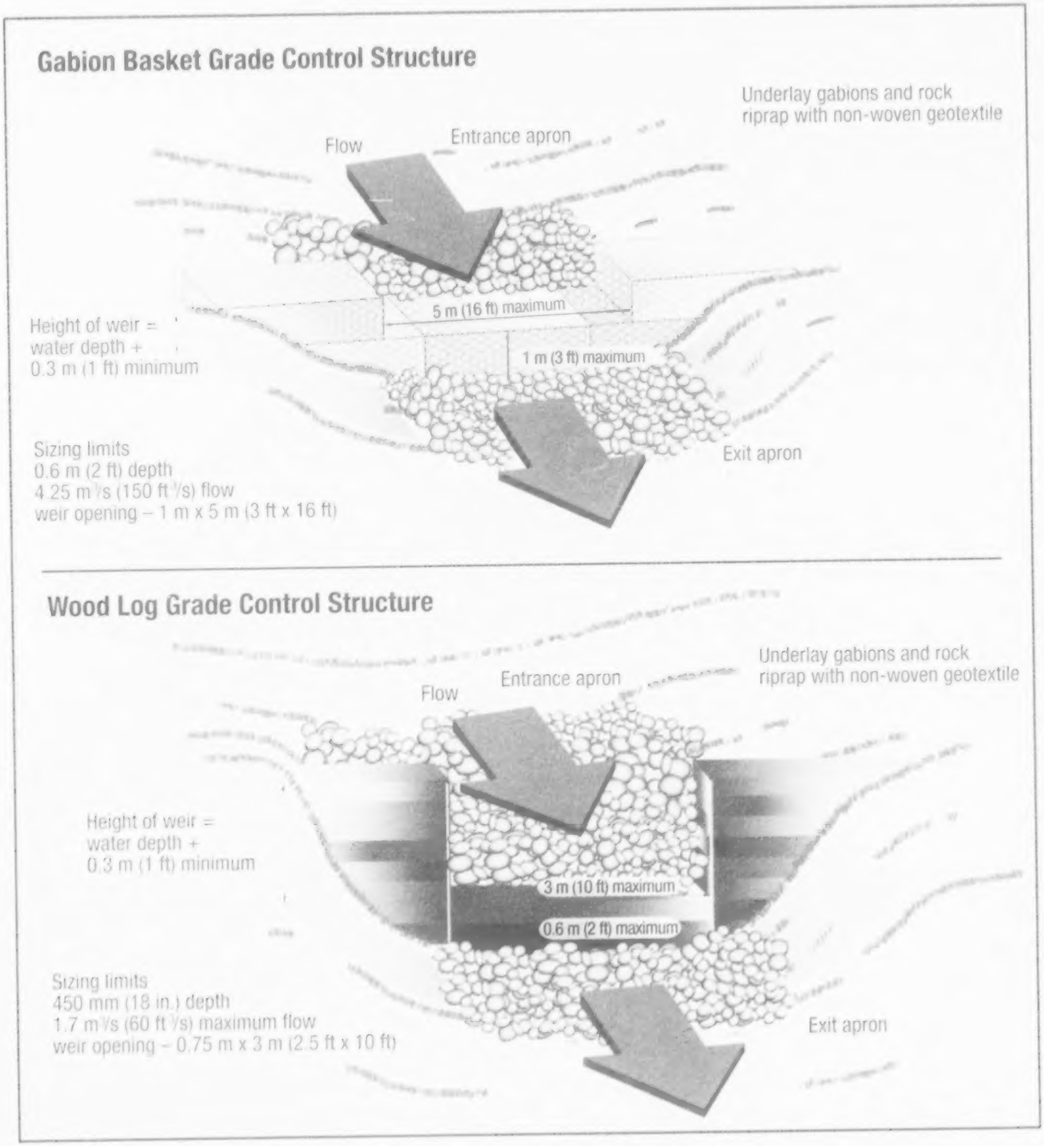


Figure 4.17. Gabion Basket and Wood Log Grade Control Structures

Conditions Where Applicable

Practical agricultural parameters limit the use of grade control structures – as described in this section – to low vertical drops and intermittent flows. Although there is no known reference stating maximum vertical drops and flows, use the following guidelines:

- For log type structures, limit drops to about 0.60 m (2 ft), depth of flow to about 0.45 m (1.5 ft), width of weir to about 3 m (10 ft) and flows up to about 1.7 m^3/s (60 ft^3/s).
- For gabion type structures, limit drops to about 1 m (3 ft), depth of flow to 0.60 m (2 ft), width of weir to 5 m (16 ft) and flows up to about 4.25 m^3/s (150 ft^3/s).

Higher drops, depths of flow and flow capacities can be accommodated but require a more detailed design, beyond the scope of this manual.

Advantages

- Log and gabion types share some advantages that make their use attractive.
- Grassed waterway grades can be reduced, encouraging smaller widths and vegetative growth.
- Abrupt grade changes can be accommodated to prevent gully erosion.
- Structures are flexible, allowing settlement or frost movement.
- Various dimensions of vertical drop or waterway width can be used.
- Installation is not difficult and relatively inexpensive compared to rock chutes.

Disadvantages

- Some maintenance is required to prevent washout around the structure.
- Use is limited to intermittent small flows.

Design Parameters

The number, location and height of drops depend on several parameters.

- Consider the existing slope of the grassed waterway. Install grade control structures at critical locations along the waterway to reduce the grade to 5% maximum, if possible.
- Match the design flow and depth of flow desired over the drop as closely as possible with the capacity, shape and dimensions of the waterway.
- Consider the amount of excavation required.
- Take into account the cropping practices to reduce straddling or crossing the structure by farm equipment.
- The size and availability of materials is important. Gabion baskets are manufactured at certain dimensions, so the actual size used in construction will be equal to and often larger than actual design requirements.

After identifying the need for one or more grade control structures, determine the design flow (see Section 2.3). Given the relatively small increase in costs, choose a return period of at least 10 years for the design flow. At this point, determine dimensions of both the depth of water over the grade control structure, and the width of the spillway weir using Table 4.23-M (4.23-I).

Table 4.23-M. Approximate Flows over a Rectangular Shaped Weir (m^3/s)

Water Depth (m)	Flow Through Weir (m^3/s)					
	1.80 m Weir Opening	2.45 m Weir Opening	3.05 m Weir Opening	3.65 m Weir Opening	4.30 m Weir Opening	4.90 m Weir Opening
0.30	0.538	0.793	0.935	1.104	1.303	1.501
0.45	0.991	1.331	1.671	2.039	2.379	2.718
0.60	1.501	2.039	2.549	3.089	3.625	4.163

Table 4.23-I. Approximate Flows over a Rectangular Shaped Weir (ft^3/s)

Water Depth (ft)	Flow Through Weir (ft^3/s)					
	6 ft Weir Opening	8 ft Weir Opening	10 ft Weir Opening	12 ft Weir Opening	14 ft Weir Opening	16 ft Weir Opening
1	19	28	33	39	46	53
1.5	35	47	59	72	84	96
2	53	72	90	109	128	147

Source: Adapted from Engineering Design Manual for Conservation Practices, U.S. Soil Conservation Service, Washington, D.C., 1984.

Design Tips

Several installation tips can help alleviate future problems.

- Stake the site well with reference heights to ensure correct elevations.
- If located on fresh fill, some settling may occur, shifting the structure. Ensure that the soil is well packed or that the structure is on virgin soil.
- Install the structure perpendicular to the waterway flow.
- Use filter cloth (see Section 3.3) liberally extending up the sides at least 1 m (3 ft) beyond the gabion baskets or logs. Continue laying the filter cloth under both the entrance apron and the exit apron to help prevent undermining. The filter cloth allows drainage through the structure while holding the soil in place. Overlap all filter cloth joints at least 0.45 m (1.5 ft).
- Extend both baskets and logs well into the channel sides (at least 1 m (3 ft)) beyond the edge of the water flow to prevent washouts around the sides (see Figure 4.17).
- Use at least 150 mm (6 in.) minus stone (see Section 3.2) for approximately 1.5 m (5 ft) both up and downstream of the structure, and about 250 mm (9 in.) deep. This will include stone up to 150 mm (6 in.) in size.
- Ensure the height of the weir is at least 0.30 m (1 ft) above the design water depth to prevent overtopping.

Grade Control Structure Design Information Sheet

1. Watershed area		____ ha	____ ac
2. Average grade of watershed			____ %
3. Runoff curve number from Tables 2.2 – 2.4			____
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)		____ m^3/s	____ ft^3/s
5. Grassed waterway dimensions (where applicable)		T = ____ m	____ ft
		D = ____ m	____ ft
6. Grade control structure vertical drop		____ m	____ ft
7. Grade control structure weir design from Table 4.23-M (4.23-I)	Weir width W	____ m	____ ft
	Water depth D	____ m	____ ft
	Weir flow	____ m^3/s	____ ft^3/s

Grade Control Structure – Example Problem #1

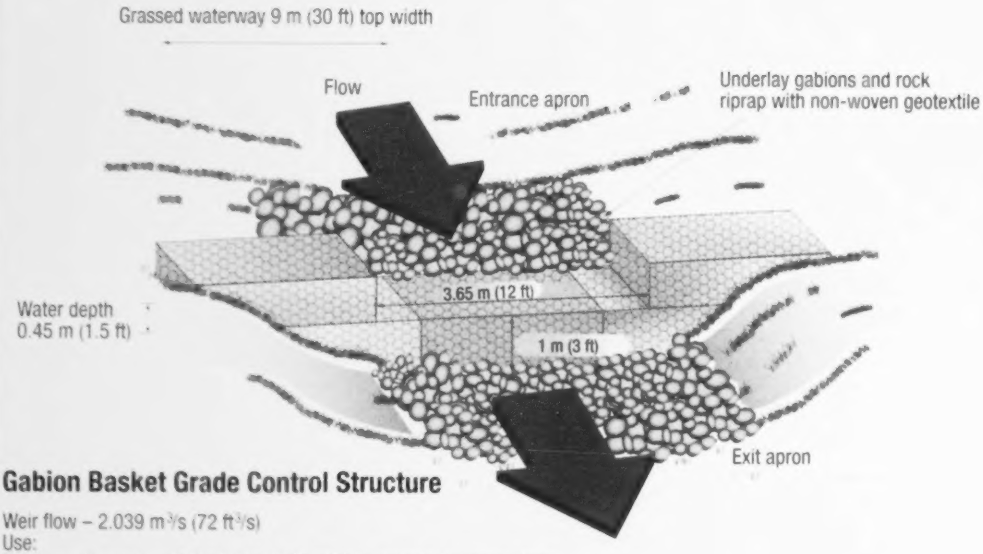
A grassed waterway requires a 1 m (3 ft) grade control structure because of an abrupt grade change at the edge of a field. The design flow is 1.7 m^3/s (60 ft^3/s) and waterway shape is about 9 m (30 ft) wide by 0.45 m (18 in.) deep. If using gabion baskets, determine the dimensions of the structure.

Solution

From Table 4.23-M (4.23-I), there is more than one weir height and width that will satisfy the flow rates required. Since the waterway is 0.45 m (18 in.) deep, choose a weir with the same or similar depth, 0.45 m (18 in.). A wider weir is more costly, so choose the smallest weir opening to accommodate the design flow, 3.65 m (12 ft). The depth of the gabions will be 1 m (3 ft) in order to permit 0.45 m (18 in.) of water to flow over the weir with 0.45 m (18 in.) of gabions above the water level to prevent overtopping. This shape will accommodate flows over 2.0 m^3/s (72 ft^3/s). Based on the width of waterway, choose two 1 m x 1 m x 4 m (3 ft x 3 ft x 12 ft) gabions as the upper layer ones to form the weir. Use three 1 m x 1 m x 3 m (3 ft x 3 ft x 9 ft) gabions for the lower layer ones to allow the 1 m (3 ft) drop. See Figure 4.18 for one possible solution.

Grade Control Structure Design Information Sheet – Example Problem #1

1. Watershed area		N/A	N/A
2. Average grade of watershed			N/A
3. Runoff curve number from Tables 2.2 – 2.4			N/A
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)		1.7 m^3/s	60 ft^3/s
5. Grassed waterway dimensions (where applicable)		T = 9 m	30 ft
		D = 0.45 m	1.5 ft
6. Grade control structure vertical drop		1 m	3 ft
7. Grade control structure weir design from Table 4.23-M (4.23-I)	Weir width W	3.65 m	12 ft
	Water depth D	0.45 m	1.5 ft
	Weir flow	2.039 m^3/s	72 ft^3/s



Gabion Basket Grade Control Structure

Weir flow – 2.039 m^3/s (72 ft^3/s)
Use:
2 – 1 m x 1 m x 4 m (3 ft x 3 ft x 12 ft) gabion baskets for upper layer
3 – 1 m x 1 m x 3 m (3 ft x 3 ft x 9 ft) gabion baskets for bottom layer

Figure 4.18. Grade Control Structure – Example Problem #1

Grade Control Structure Design Information Sheet – Example Problem #1

1. Watershed area		N/A	N/A
2. Average grade of watershed			N/A
3. Runoff curve number from Tables 2.2 – 2.4			N/A
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)		1.7 m^3/s	60 ft^3/s
5. Grassed waterway dimensions (where applicable)		T = 9 m	30 ft
		D = 0.45 m	1.5 ft
6. Grade control structure vertical drop		1 m	3 ft
7. Grade control structure weir design from Table 4.23-M (4.23-I)	Weir width W	3.65 m	12 ft
	Water depth D	0.45 m	1.5 ft
	Weir flow	2.039 m^3/s	72 ft^3/s

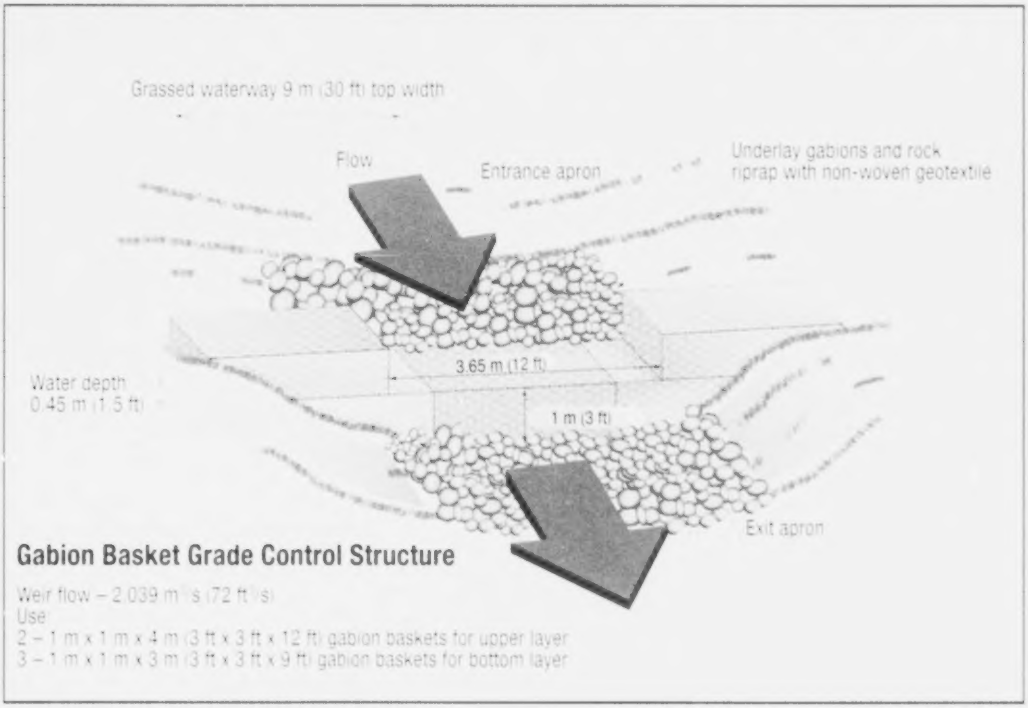


Figure 4.18: Grade Control Structure – Example Problem #1

Installation of Wood Log Grade Control Structures

1. Grade site as necessary.
2. Set 200 mm x 200 mm (8 in. x 8 in.) posts across waterway – wide enough apart to accommodate the desired weir width – to a depth of 1 m (3 ft) below the level desired on the exit apron.
3. Dig a narrow trench beside the upstream edge of the posts to the level desired on the exit apron, wide enough to permit placing the bottom log.
4. Lay filter cloth on all soil areas that will have logs or rock on them.
5. Nail logs to posts with their ends set at least 1 m (3 ft) into the bank. Stack logs high enough to allow at least 300 mm (12 in.) of logs above the design water depth. Use 100 mm x 150 mm (4 in. x 6 in.) logs on edge, or larger.
6. Don't use untreated logs for the weir – this will result in quicker rot.
7. Install the rock aprons both up and downstream of the structure. Ensure the top of the exit apron is at the level of the bottom of the bottom log.
8. Backfill and finish grading as necessary.

Grade Control Structure – Example Problem #2

An existing overland drainageway, averaging a little over 1%, has two areas where the grade picks up to over 3.5% over short 30 m (98.4 ft) stretches. Gully erosion is resulting at these locations. To protect the swale from erosion, a grassed waterway is proposed. In addition, two grade control structures are proposed to retain the 1.1% grade through the entire grassed waterway. Gabion basket structures are preferred and will be located where the gully erosion is presently occurring. A 60 ha (148 ac) watershed drains through the area, producing a design flow of 1.47 m^3/s (51.9 ft^3/s). The parabolic shaped grassed waterway dimensions include a 13 m (43 ft) top width and 0.6 m (2 ft) depth.

Solution

From Table 4.23-M (4.23-I), there is more than one weir height and width that will satisfy the flow rates required. To best meet the dimensions of the proposed grassed waterway, the weir opening will be 4.9 m (16 ft) wide and 0.30 m (1 ft) deep. Because of the width of the waterway, choose two 1 m x 1 m x 4 m (3 ft x 3 ft x 12 ft) gabions as the upper layer ones to form the weir Use three 1 m x 1 m x 3 m (3 ft x 3 ft x 9 ft) gabions for the lower layer ones to allow the 1 m (3 ft) drop.

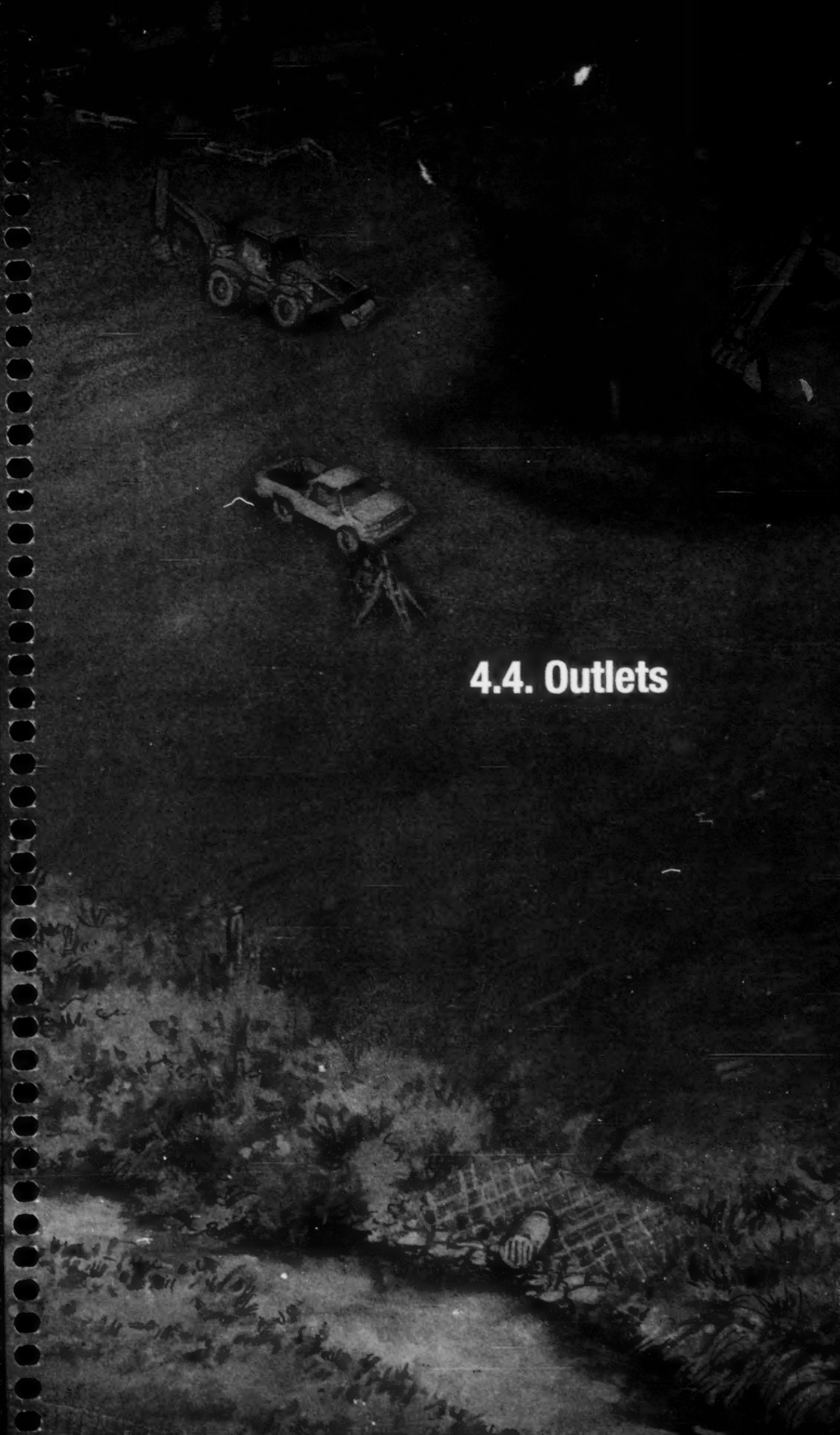
Grade Control Structure Design Information Sheet – Example Problem #2

1. Watershed area		60 ha	148 ac
2. Average grade of watershed			1.1%
3. Runoff curve number from Tables 2.2 – 2.4			80
4. Peak flow from watershed for a 10-year storm from Table 2.5-M to 2.11-M (2.5-I to 2.11-I)		1.47 m^3/s	51.9 ft^3/s
5. Grassed waterway dimensions (where applicable)		T = 13 m	43 ft
		D = 0.6 m	2 ft
6. Grade control structure vertical drop		1 m	3 ft
7. Grade control structure weir design from Table 4.23-M (4.23-1)	Weir width W	4.9 m	16 ft
	Water depth D	0.3 m	1 ft
	Weir flow	1.501 m^3/s	53 ft^3/s

Installation of Gabion Basket Grade Control Structures

1. Grade site as necessary.
2. Excavate a trench at least 1.1 m (3.5 ft) wide to the level desired downstream on the exit apron. Make it as long as necessary to ensure the base gabion allows a wide enough weir to ensure upper gabions don't overhang the base gabions by more than 1.2-1.5 m (4-5 ft), and that gabions extend well into the bank.
3. Lay filter cloth on all soil that will have rocks or gabions on it.
4. Assemble base gabion(s) in the trench using 1 m (3 ft) deep by 1 m (3 ft) wide gabions and fill them with 75-200 mm (3-8 in.) gabion stone using a front end loader. Wire the baskets closed.
5. Assemble and fill the upper layer gabions to form the required weir.
6. Install the rock riprap aprons upstream and downstream of the grade control structure. Ensure the top of the exit apron is at the level of the bottom of the base gabions.
7. Backfill and finish grading as necessary.
8. Grade control structures usually fail when water finds a path around or under the structure. If water is going around it, heighten the banks to ensure all the water travels over the weir. If water is going under the structure, look for uneven settlement as the first sign of problems or renewed gullying. If this problem is found early enough, install an impermeable cutoff wall deep below ground and upstream of the inlet to the structure to ensure water flows over the grade control structure.

4.4. Outlets



4.4 Outlets

An outlet is a transition point in any system that removes water, and results from a change in shape and/or size, change in grade, or a change from pipe to an open system. This transition or change brings the potential for erosion.

Grassed Waterway Outlets

In most cases, a grassed waterway empties into a ditch, stream or a larger grassed waterway. These outlets must be stable and non-erodible.

The grassed waterway should fan out or widen as it approaches the outlet if the grade difference is minimal. The grade in a simple grassed waterway should not exceed 5% unless special precautions are taken (e.g. rock chute, check dams, rock riprap lining), and the grade should decrease as it approaches the outlet. If large flows are anticipated, consider rock riprap, gabion or other methods to protect the channel the waterway empties into (Figure 4.19).

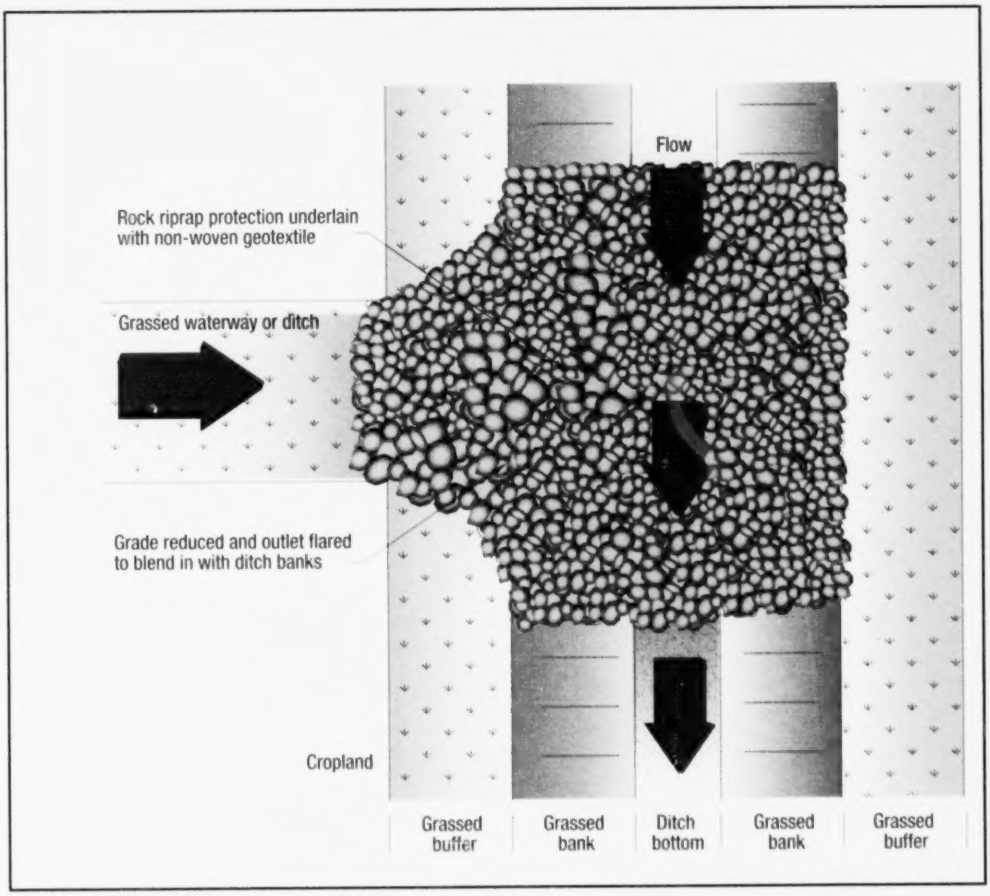


Figure 4.19. Ditch or Grassed Waterway Outlet

When the grade difference is too great between the grassed waterway and the channel it empties into, use one of the following grade control methods to prevent erosion damage:

- drop pipe structure
- gabion mat
- grade control structure
- rock chute

Be sure to erosion proof the transition from a waterway to a grade control method using recommendations in this manual.

When using a grade control method, i.e. drop pipe structure, provide some means to protect the outlet ditch that water is discharged into (Figures 4.8, 4.17 and 4.20).

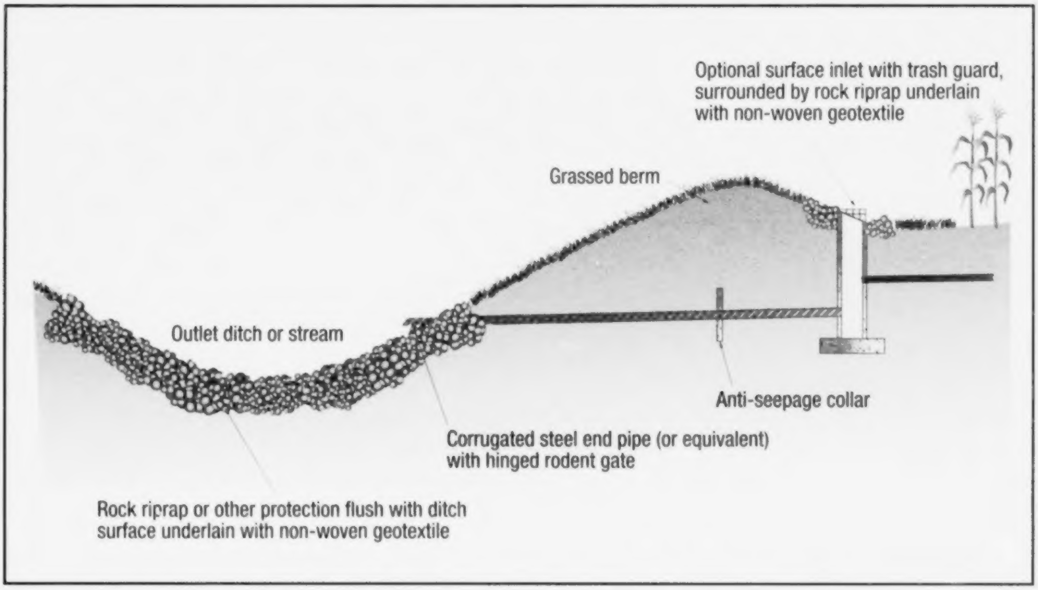


Figure 4.20. Drop Pipe Structure Outlet for Tile Drainage System

Ditch Outlets

Ditches are usually much deeper than grassed waterways. They often carry water over long periods of time and at higher velocities. Protect the ditch outlet from erosion by one or more of the following methods:

- gradual widening and increase in slope of ditch banks (e.g. from 2:1 to 4:1) approaching the ditch outlet
- decrease in grade and an increase in side slopes approaching the ditch outlet
- rock riprap or gabion mat liner in the ditch bottom
- install a drop structure where there's a drop of more than one foot at the ditch outlet, e.g. rock chute, grade control structure or a drop pipe structure (Figures 4.8, 4.17 and 4.20).

A ditch may empty into a lake or river and require protection from waves or current. If it empties into another channel, that channel may need protection from erosion (Figure 4.19).

Occasionally a ditch flows from very steep terrain to a flat area and becomes a wide, shallow grassed waterway. In every case, protect the transition area from erosion. All of the structures or procedures mentioned here are explained in detail in another part of this manual.

Tile Drainage Outfall

The outfall is the most important part of a subsurface drainage system. Take great care and attention during installation and inspect the outfall for necessary maintenance at least once a year.

Where possible, keep the number of outfalls to a minimum by using one large main (collector) line or a series of main (collector) lines. Where it's necessary to check flows or inspect submains or other drains, install a junction box. A junction box is used to empty several submains into one large main or outlet, and is constructed from well tile, a length of large metal culvert pipe, or a manufactured concrete or plastic container designed for this purpose.
Protect the outfall against erosion from water turbulence and high velocities, settlement, rodents, silting, shifting and damage by machinery.

Unprotected or improperly installed tile drainage outfalls can cause serious bank erosion and create large gullies.

Constructing a Good Tile Drainage Outfall

Protect drains that discharge into a ditch or watercourse against erosion and undermining. Use a prefabricated rigid solid plastic or metal outlet pipe as an end pipe. Protect plastic end pipes against weather, fire and animal damage, and crushing. Standard corrugated plastic tubing is not satisfactory for an end pipe. Ensure the end pipe is the proper length (see Table 4.24-M (4.24-I)), angles downstream and has a rodent gate (see Figure 4.24). Install the end pipe immediately after digging the trench, and then immediately seed the back-filled ditch bank (see Section 3.1, Ditch Bank Seeding). Ensure the end pipe discharges a minimum of 0.30 m (1 ft) above normal water level or ditch bottom (Figure 4.21).

An overhanging end pipe should discharge water at the toe of the ditch bank (Figure 4.21). If this isn't possible, use another erosion control method (see Figures 4.20, 4.25).

Protect the ditch bottom and ditch bank with rock riprap to prevent erosion (Figure 4.21). Ensure the rock riprap is a minimum of 1.5 m (5 ft) wide across the ditch bottom and up the other bank. Use field stone as riprap if it's broken or irregularly shaped and hand placed. See Section 3.2 or OMAFRA Factsheet, *Use of Rock in Erosion Control Projects*, Order No. 90-227.

Where ice damage could occur, construct the end pipe flush with the ditch bank. Install rock riprap around and below the end pipe to prevent erosion (Figure 4.22).

Where butt joints are used, they must be accurately aligned and secured. Install a leak-proof collar, such as a prefab collar, to prevent joint misalignment. Where sleeve joints are used, use some form of gasket to make the joint leak proof. Ensure the joint is accurately aligned, secured and sealed on the outside.

The backfill material over the joint and the end pipe should be well compacted to prevent shifting and discourage erosion around the pipe. In some situations, an anti-seepage collar is required on the outlet pipe (Figure 4.23). These collars are manufactured of concrete, metal or plastic, and measure 1.4 m x 1.4 m (4.5 ft x 4.5 ft) on a typical tile drainage outfall. A rodent gate on the end pipe is essential – attach it when the outlet is installed. Hinge the gate to allow cleaning, and include openings with a maximum width of 25 mm (1 in.) (Figure 4.24).

When constructing a tile drainage outfall in a very high ditch bank, prevent erosion with the following methods.

- Use a properly designed drop pipe structure to bring the water down, sized large enough to serve as a junction box for several main lines. For an optional surface water inlet, see Figure 4.20 and refer to OMAFRA Factsheet, *Drop Inlet Spillways,* Order No. 85-057. Don't install this surface inlet if the tile drain will have continuous winter flow (e.g. springs) – this can cause blockage by ice buildup.
- Install a non-perforated main and outlet as shown in Figure 4.25.

No surface flow should enter the ditch at the same location as the end pipe location. Where it's necessary to allow surface water to enter a ditch, construct a properly designed drop structure. For reference, refer to Figure 4.20, Section 4.3 or OMAFRA Factsheets, *Gabion Basket Drop Structures Along Waterways,* Order No. 99-049 and *Use of Rock in Erosion Control Projects,* Order No. 90-227.

Indicate the location of all end pipes by a marker that's highly visible above crops and grass (Figure 4.26). Keep tile drain outlets clean so the drainage system will function properly. Do a spring and fall inspection to check for silting, debris, erosion, settlement and misalignment. Correct all problems immediately.

Table 4.24-M. Suggested Dimensions of Corrugated Steel Pipe for Butt Joints and Sleeve Joints

Nominal Drainpipe Diameter (mm)	End Pipe Dimensions*			
	Minimum Diameter (mm)		Minimum Length[1] (mm)	Maximum Cantilever (mm)
	Butt Joint	Sleeve Joint		
100	100	Maximum outside diameter of drainpipe + 50 mm	3,000	400
150	150		3,000	600
200	200		3,000	600
250	250		3,600	600
300	300		3,600	800
350	350		4,800	800
400	400		5,400	800
450	450		6,000	1,000

Table 4.24-I. Suggested Dimensions of Corrugated Steel Pipe for Butt Joints and Sleeve Joints

Nominal Drainpipe Diameter (in.)	End Pipe Dimensions*			
	Minimum Diameter (in.)		Minimum Length[1] (in.)	Maximum Cantilever (in.)
	Butt Joint	Sleeve Joint		
4	4	Maximum outside diameter of drainpipe + 2 in	10	16
6	6		10	24
8	8		10	24
10	10		12	24
12	12		12	32
14	14		16	32
16	16		18	32
18	18		20	40

*These are minimum pipe dimensions; product availability may necessitate using a larger diameter or length. Butt joints should be accurately aligned and held securely with a leak-proof collar.

[1] Minimum length of pipe represents minimum length in ditch bank. If using cantilever outfall, the maximum cantilever column measurements are added to the minimum length in order to obtain overall length of end pipe.

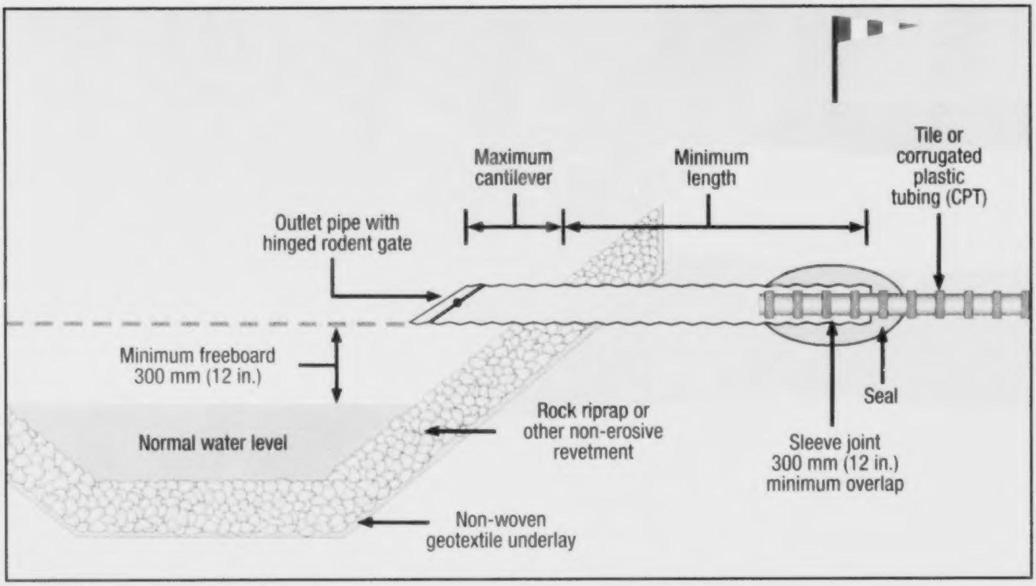


Figure 4.21. Well Constructed Tile Drain "Cantilever Type" Outfall

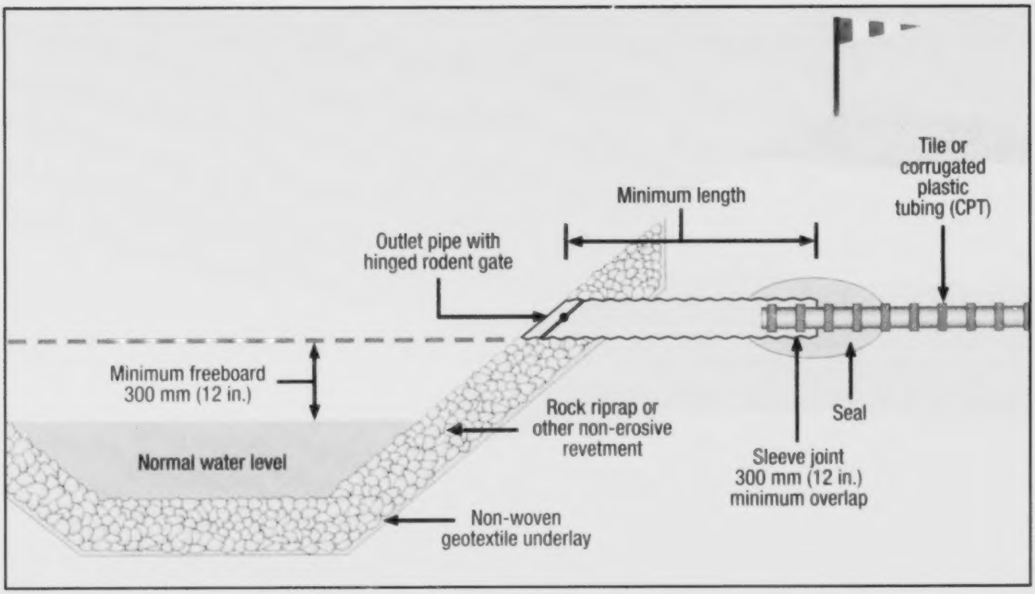


Figure 4.22. Well Constructed Tile Drain "Flush Type" Outfall

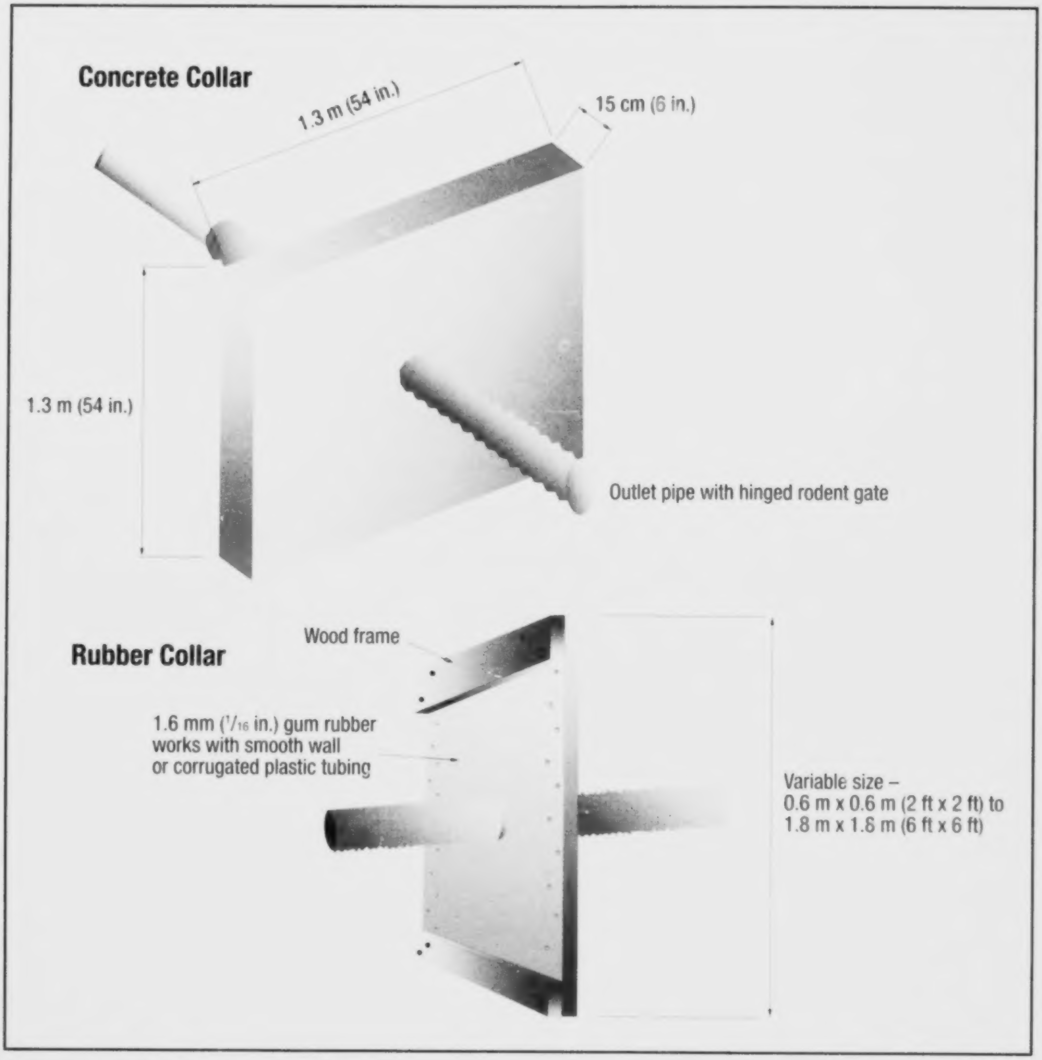


Figure 4.23. Anti-seepage Collars

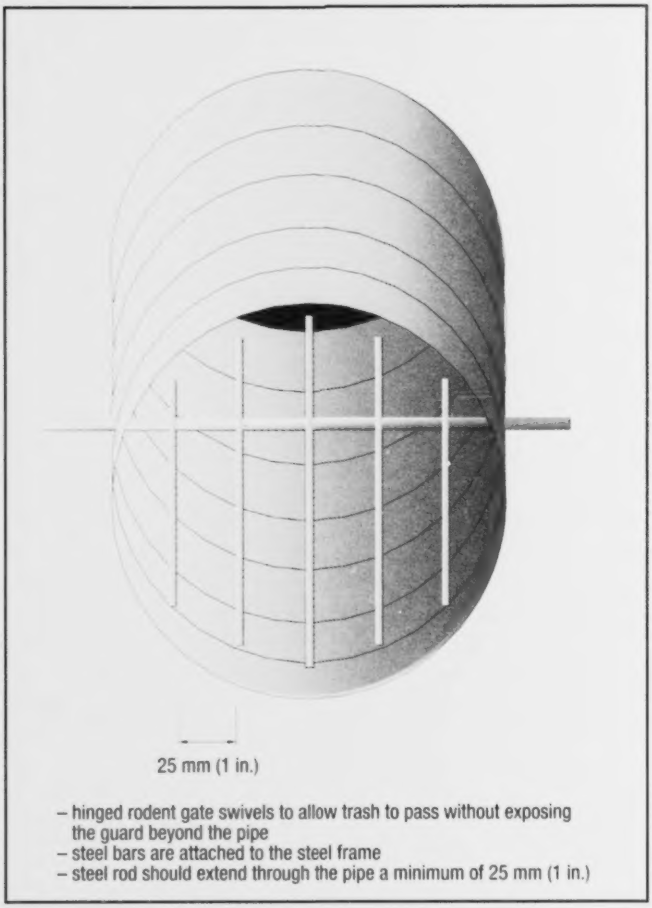


Figure 4.24. Hinged Swinging Rodent Gate

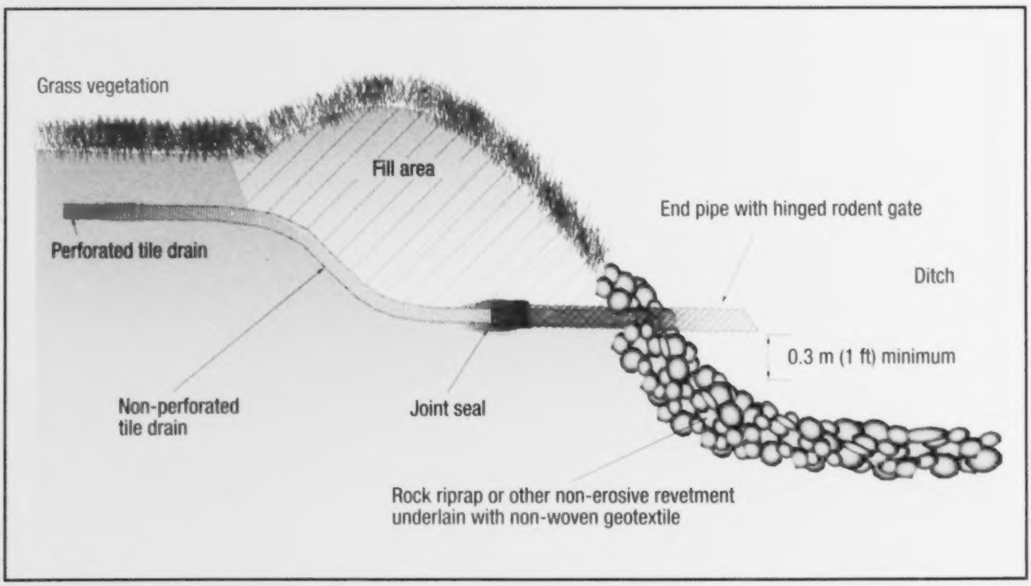


Figure 4.25. Sloped Pipe Outlet

Figure 4.26. Outlet Marker

4.5 Water and Sediment Control Basins

A water and sediment control basin (WASCoB) is a method of erosion control that involves constructing an earthen embankment or berm across a natural drainageway to intercept surface runoff, and then slowly releasing the temporarily ponded runoff water into an underground drainage system. A WASCoB is also referred to as a channel terrace.

More extensive versions of the same erosion control approach used by the WASCoB are commonly referred to as field terracing and diversion terracing. Although field and diversion terraces are similar in design and construction to the WASCoB, each of these structural measures serves different purposes.

The following sections provide a brief description of field and diversion terracing, as well as WASCoBs. The WASCoB is more applicable to Ontario and is the main design focus in this manual. Field and diversion terracing systems are complex. Begin construction only after a careful design is completed by a professional engineer with experience in terracing.

A dependable outlet is needed, whether a terrace or WASCoB is constructed. Grassed waterways are sometimes used as outlets, but a tile drain outlet is used most often in Ontario. Structures commonly used as tile drain inlets for WASCoB projects include a small capacity riser pipe, concrete or plastic catch basin, or a blind inlet (Figure 4.27).

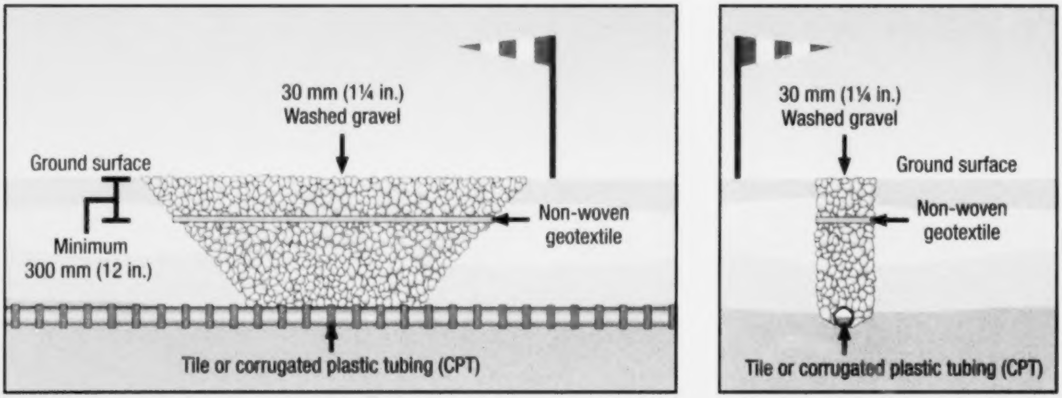


Figure 4.27. Blind Inlet to Tile Drain

Field Terracing

A field terrace is an earthen embankment, or a ridge and channel, constructed across the slope at a suitable location to intercept surface water runoff. It is usually constructed with an acceptable lateral grade to an outlet (surface or subsurface). Field terraces are usually designed to shorten the slope length and sometimes reduce the slope itself (if benched) to reduce sheet erosion rates (Figure 4.28).

Where applicable, terraces are one of the best mechanical erosion control practices. For farmers to adopt this practice, field terracing must have a desirable shape and alignment, and be farmable with modern equipment. The way a terrace berm is constructed will determine if it can be farmed or not (Figure 4.29).

Gradient Terraces with Waterway Outlet

Gradient Terrance with Tile Outlets

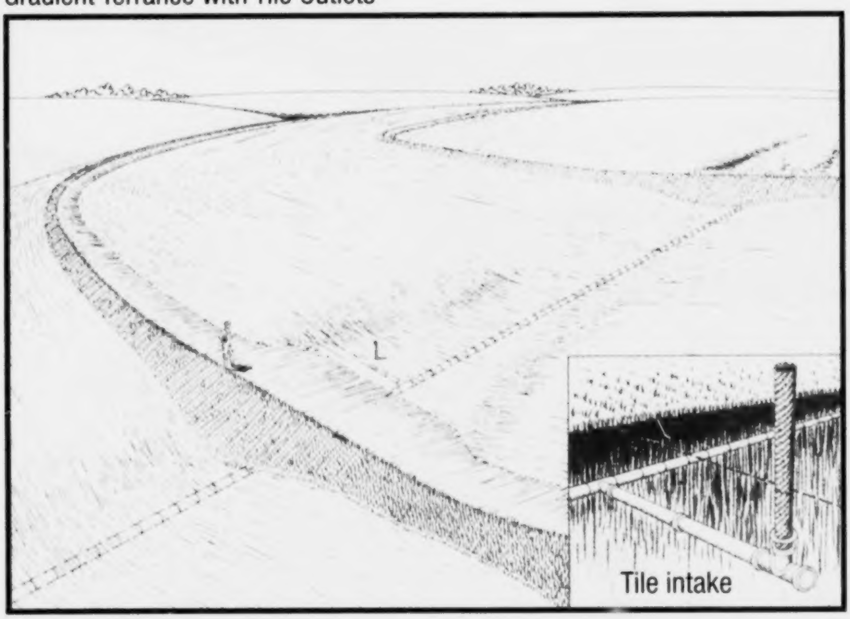


Figure 4.28. Gradient Terrace System

Field terracing is meant for moderately sloped (usually 0.5% to 8%), non-stony lands with reasonably deep soils and simple topography. It's a relatively expensive measure, making it only feasible on highly productive lands. Only consider terracing where annual erosion rates don't exceed 6.5 tonnes/ha (3 tons/ac). Conservation cropping and tillage are also typically part of a terracing system plan.

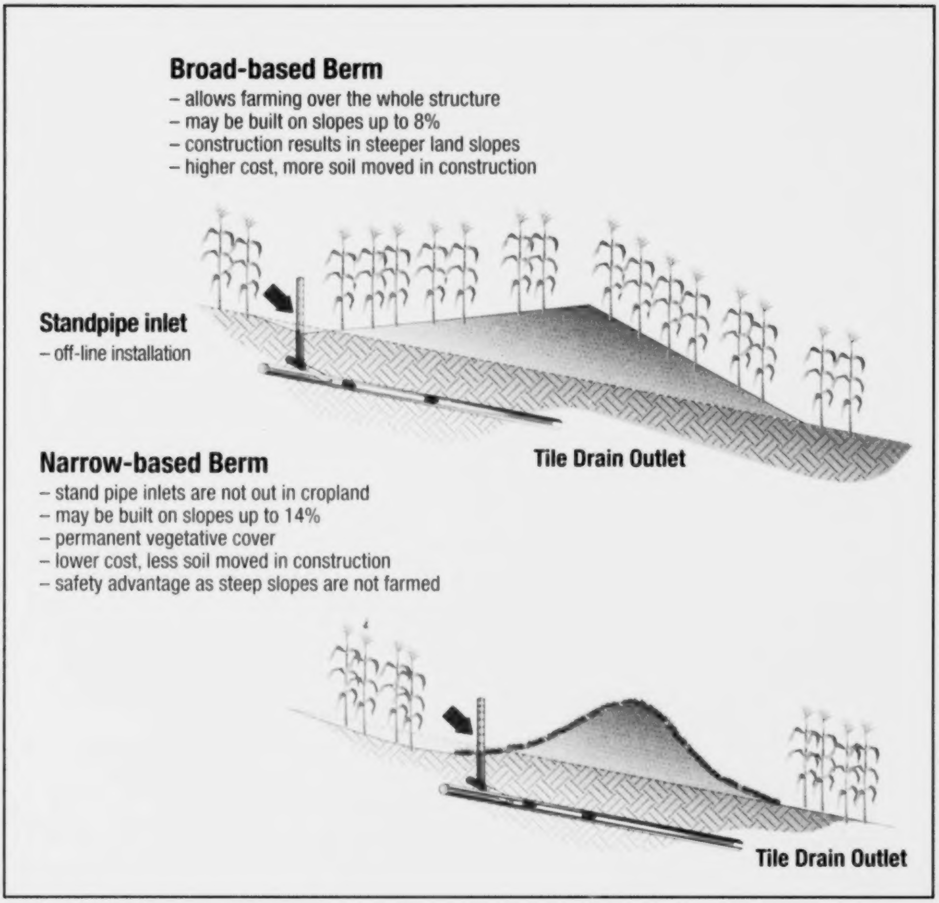


Figure 4.29. Types of Berms

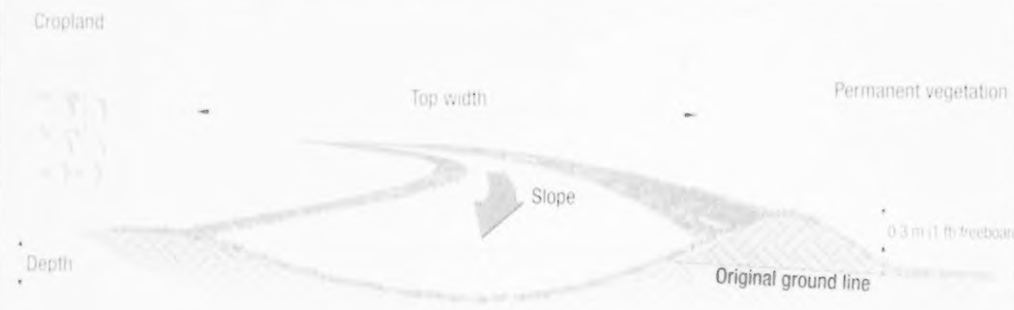
Diversion Terraces

A diversion terrace consists of a permanently vegetated diversion channel in combination with a supporting berm on the downslope side, laid out across the slope (Figure 4.30).

Diversion terraces provide sheet erosion control benefits similar to field terraces, on a smaller scale. In areas where land is too irregular for complete field terracing, or the landbase doesn't require such an elaborate system, diversion terraces are an alternative.

Diversion terraces prevent rill erosion and reduce sheet erosion by intercepting hillside runoff, then redirecting it into a designed channel to a stable outlet. Diversion terraces also prevent gully erosion by redirecting surface water across the slope away from the head of a gully.

Diversion terraces also divert runoff away from or around a manure storage, livestock yard or other area where there is a risk of relatively clean water becoming contaminated as it passes through.



Parabolic Cross-section

A WASCoB is designed to address downstream rill/gully erosion and may replace the need for a grassed waterway, a rock chute or even a standard catch basin in some areas. Use a WASCoB for smaller watersheds of less than 20 ha (50 ac). The system works by ponding the total expected runoff from a 10-year design storm, and releasing the water through a tile system in a desired length of time, typically less than 24 hours. Additional storage in the ponding area allows for 15 years of sediment buildup originating from the pond's watershed.

A landowner must accept flooding for a determined period of time (12-24 hours). Consider another method of erosion control if this length of flooding isn't acceptable. WASCoB works well on watersheds less than 20 ha (50 ac). If a large watershed is involved, divide into several small watersheds by constructing a series of WASCoBs along the drainageway.

The WASCoB design approach and associated design information sheet in this manual allows for watersheds less than 20 ha (50 ac), storages of up to 2,830 m³ (100,000 ft³) and pond depths of up to 2.1 m (7 ft). Exceeding any one of these criteria will require a revised system or assistance from a professional erosion control engineer experienced in the design of larger systems.

- Achieves the same objective as a grassed waterway without the land area required and the problems associated with a grassed waterway.
- Reduces the plugging potential at the drop pipe inlet grate. Ponding slows down the flow of water, allowing debris and sediment to settle out before reaching the grate.
- Removes a high percentage of the coarser sediment carried by the runoff water being ponded.
- Diverts water flow to a less erodible location.
- Outlet flows are normally small, allowing small diameter tile systems to be used for outlets.
- The storage buffers the peak flow expected downstream.

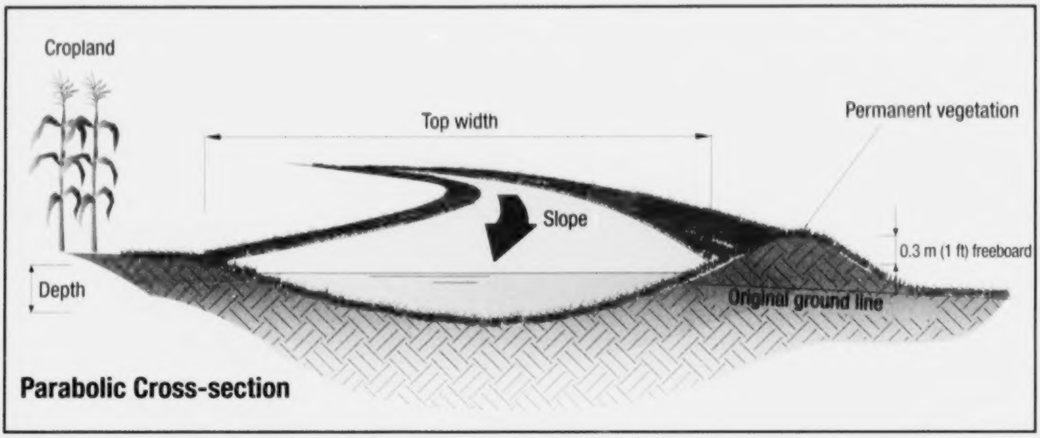


Figure 4.30. Diversion Terrace Cross-section

Water and Sediment Control Basin System (WASCoB)

A WASCoB is designed to address downstream rill/gully erosion and may replace the need for a grassed waterway, a rock chute or even a standard catch basin in some areas. Use a WASCoB for smaller watersheds of less than 20 ha (50 ac). The system works by ponding the total expected runoff from a 10-year design storm, and releasing the water through a tile system in a desired length of time, typically less than 24 hours. Additional storage in the ponding area allows for 15 years of sediment buildup originating from the pond's watershed.

Conditions Where Applicable

A landowner must accept flooding for a determined period of time (12-24 hours). Consider another method of erosion control if this length of flooding isn't acceptable. WASCoB works well on watersheds less than 20 ha (50 ac). If a large watershed is involved, divide into several small watersheds by constructing a series of WASCoBs along the drainageway.

Design Limits of Metholodgy Described in This Manual

The WASCoB design approach and associated design information sheet in this manual allows for watersheds less than 20 ha (50 ac), storages of up to 2,830 m^3 (100,000 ft^3) and pond depths of up to 2.1 m (7 ft). Exceeding any one of these criteria will require a revised system or assistance from a professional erosion control engineer experienced in the design of larger systems.

Advantages of a Water and Sediment Control Basin System

- Achieves the same objective as a grassed waterway without the land area required and the problems associated with a grassed waterway.
- Reduces the plugging potential at the drop pipe inlet grate. Ponding slows down the flow of water, allowing debris and sediment to settle out before reaching the grate.
- Removes a high percentage of the coarser sediment carried by the runoff water being ponded.
- Diverts water flow to a less erodible location.
- Outlet flows are normally small, allowing small diameter tile systems to be used for outlets.
- The storage buffers the peak flow expected downstream.

Disadvantages of a Water and Sediment Control Basin System

- Temporary flooding will occur, possibly causing limited crop damage.
- Cost can be prohibitive, especially if high berms are required.
- Problems can occur if the water overtops the storage due to an extremely large storm, plugged outlet system or design error. An emergency spillway is necessary.
- Proper design of the system is essential.
- Berms (especially narrow based) are vulnerable to rodent damage which could cause failure of the berm.
- Broad based berms should normally only be cultivated parallel to the top of the berm.
- In situations where manure, fertilizers or pesticides are applied to a field, the stand pipe inlet can provide a direct pathway for these pollutants to enter surface water.

WASCoB Design

To design a water and sediment control basin, complete the following steps.

1. Determine the potential location of the earthen berm.
2. Obtain the watershed area and watershed slope above the proposed storage. If the watershed area is equal to or greater than 20 ha (50 ac), relocate the storage higher in the watershed or use another erosion control approach.
3. Determine the runoff curve number using the watershed's characteristics (Tables 2.2-2.4).
4. Obtain the peak flows for both the 10- and 25-year storms as well as the 10-year storm duration and the 10-year storm volume from Tables 4.25-M to 4.31-M (4.25-I to 4.31-I). If the storm volume is higher than 2,830 m^3 (100,000 ft^3), relocate the WASCoB.
5. Accurately determine the upstream pond slope and side pond slopes. If the side slopes are different, average the side slopes. If the side slopes vary by more than 50%, separate the sides and calculate individually.
6. Determine the soil loss expected in the watershed above the storage using Table 4.32-M (4.32-I). If the expected soil loss exceeds 6.5 tonnes/ha (3 tons/ac), advise the landowner to consider changing cropping practices to reduce soil loss. If Table 4.32-M (4.32-I) does not have the needed combination of information, ask an OMAFRA crop technology specialist or an OMAFRA engineer.
7. Determine the storage required to store 15 years of eroded soil.
8. Determine the total storage required by adding the expected water volume to the expected eroded soil volume.
9. Obtain the volume factor by multiplying the total storage required by the average of the pond's two side slopes (%). Then multiply this number by the upstream pond slope (%).
10. Determine the pond depth by referring to Table 4.33-M (4.33-I). If pond depth exceeds 2.1 m (7 ft), relocate storage further upstream or use another erosion control approach.
11. Determine the pond dimensions by dividing pond depth by the side and upstream pond slopes (if the side slopes vary by more than 50%, separate the sides and calculate individually).
12. Obtain the maximum flooding time from Table 4.34.
13. Determine the outlet capacity by dividing the required water storage by the maximum flooding time (less the storm duration).
14. Determine the outlet size using information on drop pipe inlets from Table 4.18-M (4.18-I), Figure 4.31 or Figure 4 in OMAFRA Publication 29, *Drainage Guide for Ontario*. If designing a multiple WASCoB system, ensure the tile outlet capacity increases for each WASCoB moving downslope.

15. Determine which type of emergency overflow spillway is required. On a low risk structure, a grassed lined emergency overflow spillway is adequate. For high risk structures, use a rock lined emergency overflow spillway.
16. Determine the capacity of the emergency overflow spillway. The emergency overflow spillway is designed for a 25-year storm. Use information from Section 4.3.1 and 4.3.3 and refer to Table 4.35-M (4.35-I) to complete the emergency overflow spillway design.
17. Determine the final berm dimensions and earth volume required to construct the berm.

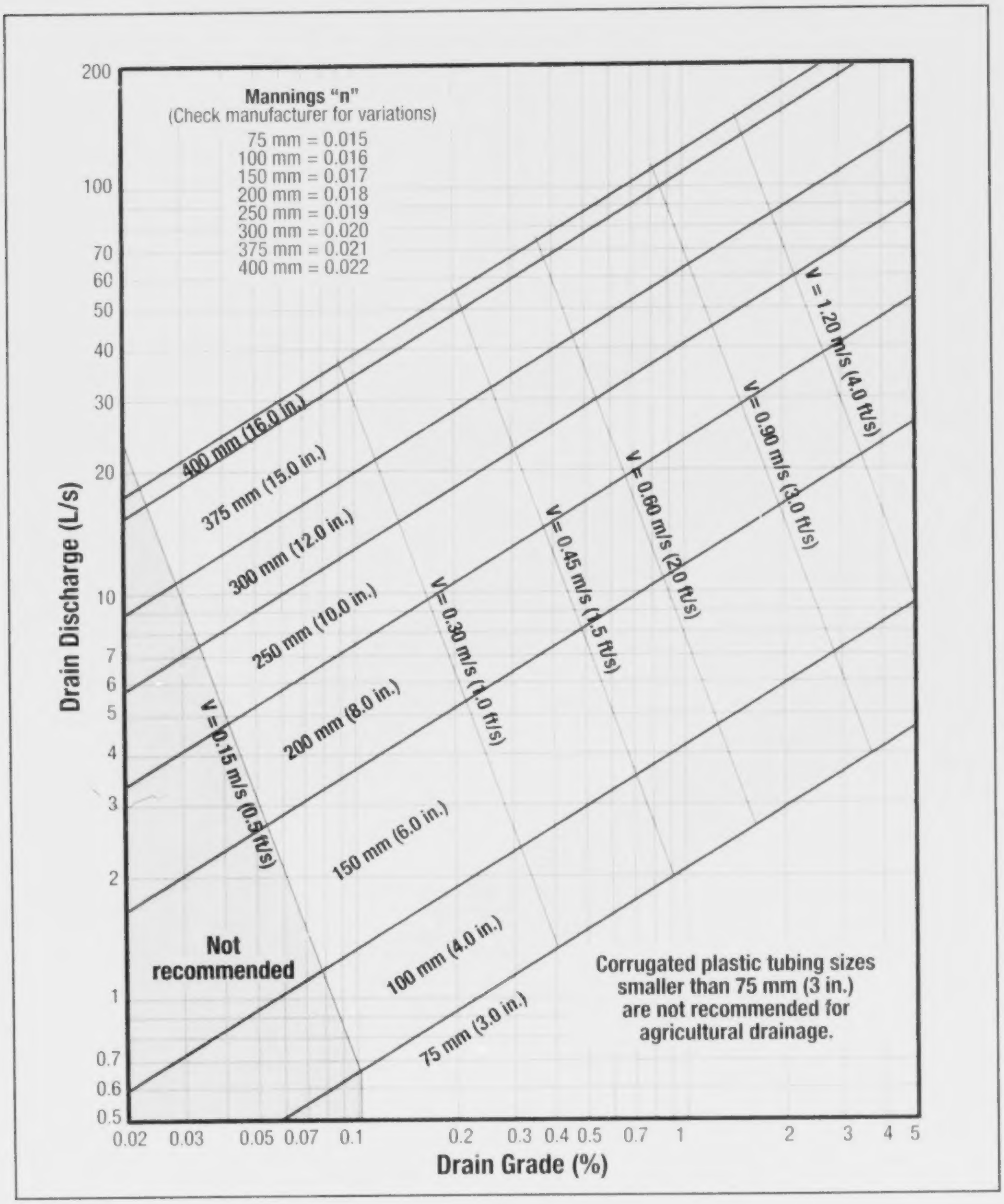


Figure 4.31 Determination of Tile Size

15. Determine which type of emergency overflow spillway is required. On a low risk structure, a grassed lined emergency overflow spillway is adequate. For high risk structures, use a rock lined emergency overflow spillway.
16. Determine the capacity of the emergency overflow spillway. The emergency overflow spillway is designed for a 25-year storm. Use information from Section 4.3.1 and 4.3.3 and refer to Table 4.35-M (4.35-I) to complete the emergency overflow spillway design.
17. Determine the final berm dimensions and earth volume required to construct the berm.

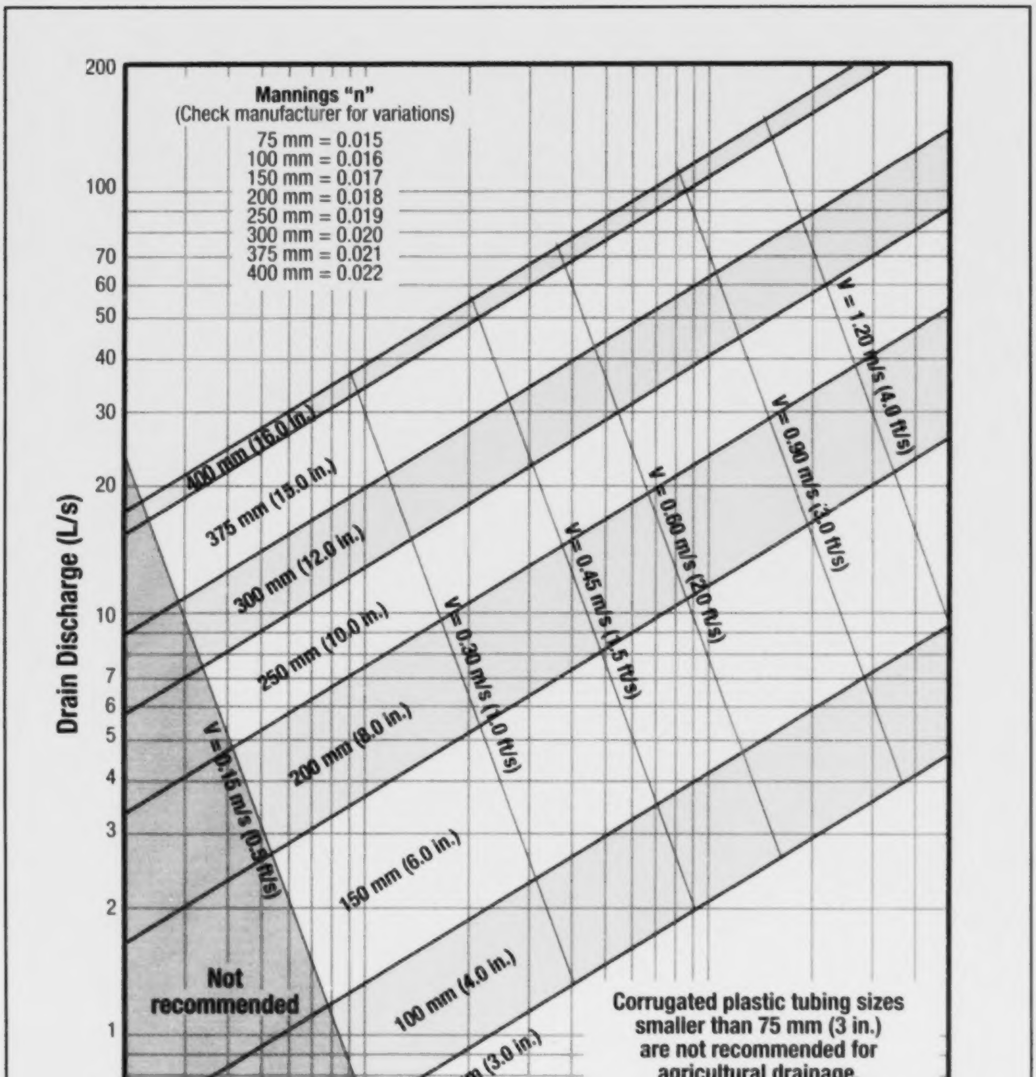


Figure 4.31. Determination of Tile Size

Water and Sediment Control Basin (WASCoB) Design Information Sheet (Single WASCoB System)

Note: Use this Design Information Sheet if only **one** WASCoB is to be constructed and drained through a single subsurface tile outlet.

WASCoB Identification ____

1. Watershed area	____ ha	____ ac
2. Watershed slope		____ %
3. Runoff curve number from Tables 2.2 – 2.4		____
4. Peak flow from watershed for 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	____ m^3/s	____ ft^3/s
5. Peak flow from watershed for 25-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	____ m^3/s	____ ft^3/s
6. Obtain the storm duration for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)		____ hrs
7. Obtain the storm volume expected for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	____ m^3	____ ft^3
8. Determine slope of ponding area upstream from storage berm from field measurements		____ %
9. Determine slope of side of ponding area upstream from storage berm from field measurements. If side slopes are different use the average of the two slopes.		____ %
10. Determine soil loss expected above ponding area from Table 4.32-M (4.32-I)	____ tonnes/ha/yr	____ tons/ac/yr
11. Storage required for eroded soil for 15-year life expectancy Line (10) x Line (1) x 15 = ____ x ____ x 15 = ____ tonnes x 0.68 m^3/tonne = ____ m^3 (____ x ____ x 15 = ____ tons x 21.7 ft^3/ton = ____ ft^3)	____ m^3	____ ft^3
12. Total pond storage Line (7) + Line (11) = ____ + ____ = ____ m^3 (____ ft^3)	____ m^3	____ ft^3
13. Determine volume factor Line (12) x Line (8) x Line (9) = ____ x ____ x ____ = ____ m^3 (____ ft^3)	____ m^3	____ ft^3
14. Obtain pond depth (design berm height) from Table 4.33-M (4.33-I)	____ m	____ ft
15. Determine pond length $\frac{\text{Line (14)}}{\text{Line (8)}}$ x 100 = ____ x 100 = ____ m (____ ft)	____ m	____ ft
16. Determine maximum pond width $\frac{\text{Line (14)}}{\text{Line (9)}}$ x 200 = ____ x 200 = ____ m (____ ft) If pond side slopes vary by more than 50%, the calculated pond width will be different than the actual field pond width. For accuracy, separate the sides and calculate individually.	____ m	____ ft

17. Obtain maximum flooding time from Table 4.34	____ hrs	
18. Determine outlet capacity $\frac{\text{Line (7)}}{\text{Line (17)} - \text{Line (6)}}$ x 0.000277 = $\frac{\_\_\_\_\_\_}{\_\_\_\_ - \_\_\_\_}$ x 0.000277 = ____ m³/s (____ ft³/s)	____ m³/s	____ ft³/s
19. Determine the riser pipe and horizontal pipe sizes. Complete the following:		
– horizontal pipe slope	____ %	
– horizontal pipe diameter (Table 4.18-M (4.18-I)) or Figure 4.31 or OMAFRA Publication 29, *Drainage Guide for Ontario*	____ mm	____ in
– riser pipe diameter (Tables 4.19-M to 4.22-M (4.19-I to 4.22-I))	____ mm	____ in
– orifice diameter (if required) (Tables 4.21-M to 4.22-M (4.21-I to 4.22-I))	____ mm	____ in
20. Check emergency overflow spillway type to be used	❑ Grass lined	❑ Rock lined
21. Determine emergency overflow spillway capacity from Line (5)	____ m³/s	____ ft³/s
22. Determine emergency overflow spillway notch dimensions from Table 4.35-M (4.35-I) to meet capacity requirements from Line (21)		
– notch width (L)	____ m	____ ft
– notch depth (D)	____ m	____ ft
23. Actual berm height (Note: Freeboard is 10% of Line (14) to maximum of 0.15 m (6 in.)) Line (14) + freeboard + notch depth (D) (Line (22)) = ____ + ____ + ____ = ____ m (____ ft)	____ m	____ ft
24. Actual berm length $\frac{\text{Line (23)}}{\text{Line (9)}}$ x 200 = ____ x 200 = ____ m (____ ft)	____ m	____ ft
25. Berm side slope (minimum 2:1, maximum 8:1)	____ :1	
26. Top width of berm (Note: Default width of 1.2 m (4 ft))	1.2 m	4 ft
27. Bottom width of berm Line (26) + (2 x Line (23) x Line (25)) = ____ + (2 x ____ x ____) = ____ m (____ ft)	____ m	____ ft
28. Earth volume for berm from Table 4.36-M to 4.38-M (4.36-I to 4.38-I)	____ m³	____ yd³

Water and Sediment Control Basin (WASCoB) Design Information Sheet (Multiple WASCoB System)

Note: Use this Design Information Sheet for **each** WASCoB if more than one WASCoB is to be constructed and drained through a single subsurface tile outlet. Start at uppermost WASCoB.

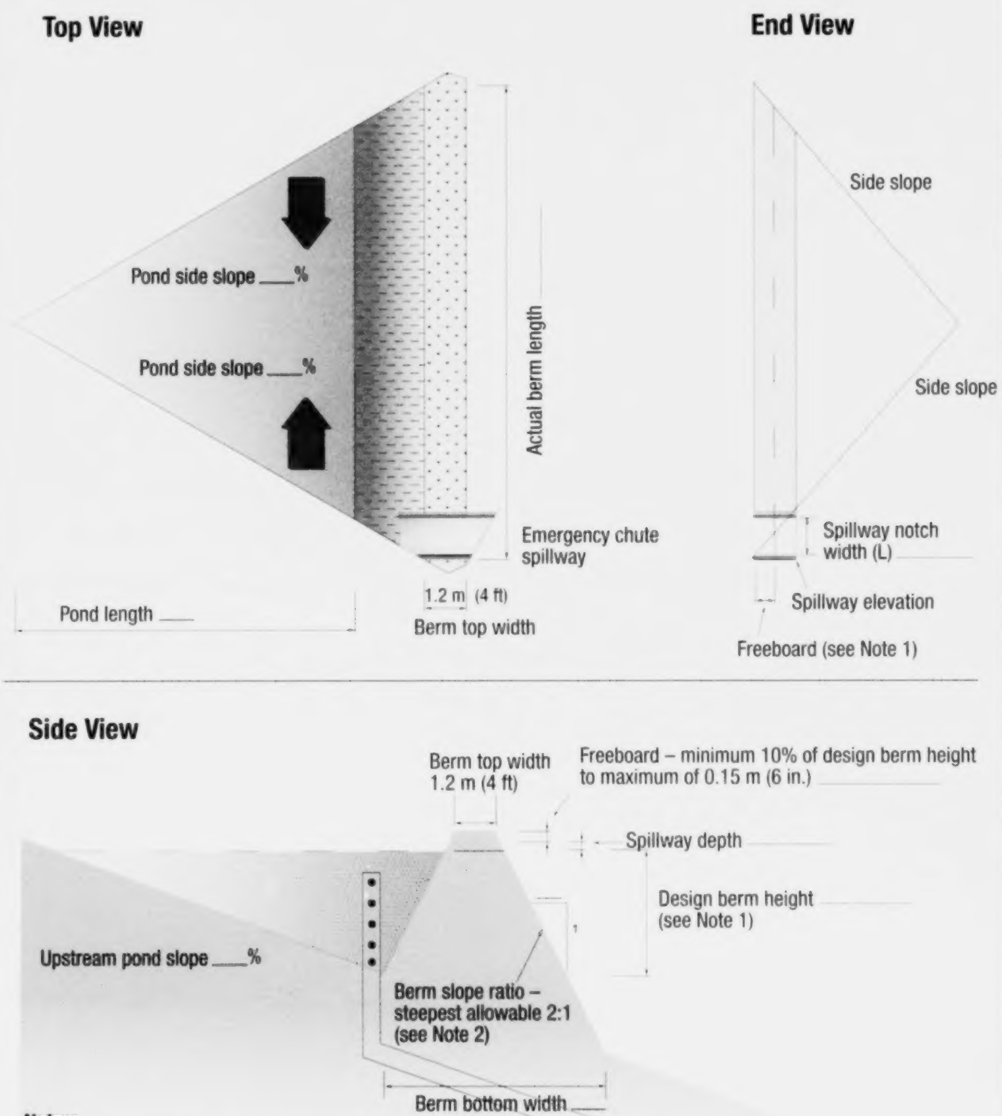
WASCoB Number_____ of _____

1. Watershed area	_____ ha	_____ ac
2. Watershed slope		_____ %
3. Runoff curve number from Tables 2.2 – 2.4		_____
4. Peak flow from watershed for 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	_____ m^3/s	_____ ft^3/s
5. Peak flow from watershed for 25-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	_____ m^3/s	_____ ft^3/s
6. Obtain the storm duration for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)		_____ hrs
7. Obtain the storm volume expected for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	_____ m^3	_____ ft^3
8. Determine slope of ponding area upstream from storage berm from field measurements		_____ %
9. Determine slope of side of ponding area upstream from storage berm from field measurements. If side slopes are different use the average of the two slopes.		_____ %
10. Determine soil loss expected above ponding area from Table 4.32-M (4.32-I)	_____ tonnes/ha/yr	_____ tons/ac/yr
11. Storage required for eroded soil for 15-year life expectancy Line (10) x Line (1) x 15 = _____ x _____ x 15 = _____ tonnes x 0.68 m^3/tonne = _____ m^3 (_____ x _____ x 15 = _____ tons x 21.7 ft^3/ton = _____ ft^3)	_____ m^3	_____ ft^3
12. Total pond storage Line (7) + Line (11) = _____ + _____ = _____ m^3 (_____ ft^3)	_____ m^3	_____ ft^3
13. Determine volume factor Line (12) x Line (8) x Line (9) = _____ x _____ x _____ = _____ m^3 (_____ ft^3)	_____ m^3	_____ ft^3
14. Obtain pond depth (design berm height) from Table 4.33-M (4.33-I)	_____ m	_____ ft
15. Determine pond length $\frac{\text{Line (14)}}{\text{Line (8)}}$ x 100 = _____ x 100 = _____ m (_____ ft)	_____ m	_____ ft
16. Determine maximum pond width $\frac{\text{Line (14)}}{\text{Line (9)}}$ x 200 = _____ x 200 = _____ m (_____ ft) If pond side slopes vary by more than 50%, the calculated pond width will be different than the actual field pond width. For accuracy, separate the sides and calculate individually.	_____ m	_____ ft

17. Obtain maximum flooding time from Table 4.34	____ hrs		
18. Determine outlet capacity $\frac{\text{Line (7)}}{\text{Line (17) – Line (6)}}$ x 0.000277 = $\frac{\_\_\_\_\_\_}{\_\_\_ - \_\_\_}$ x 0.000277 = ____ m^3/s (____ ft^3/s)		____ m^3/s	____ ft^3/s
19. Horizontal pipe capacity required (this WASCoB from Line (18))		____ m^3/s	____ ft^3/s
20. Riser pipe diameter required (this WASCoB) from Table 4.19-M to 4.20-M (4.19-I to 4.20-I)		____ mm	____ in.
21. Maximum flow through riser pipe (this WASCoB) from Table 4.19-M to 4.20-M (4.19-I to 4.20-I)		____ m^3/s	____ ft^3/s
22. If applicable, orifice plate diameter used (this WASCoB) from Table 4.21-M to 4.22-M (4.21-I to 4.22-I) (attempt to equal or slightly exceed Line (19) value)		____ mm	____ in.
23. If applicable, maximum flow through riser pipe orifice plate (this WASCoB) from Table 4.21-M – 4.22-M (4.21-I – 4.22-I)		____ m^3/s	____ ft^3/s
24. Horizontal pipe flow from Line (31) for upper WASCoB(s) (enter 0 if this is the upper WASCoB)		____ m^3/s	____ ft^3/s
25. Minimum horizontal pipe flow (below this WASCoB, i.e., including this WASCoB + upper WASCoB flows) Line (19) + Line (24) = ____ + ____ = ____ m^3/s (____ ft^3/s)		____ m^3/s	____ ft^3/s
26. Minimum horizontal pipe slope (below this WASCoB)	____ %		
27. Horizontal pipe size required (below this WASCoB) using flow from Line (25), pipe slope from Line (26) and Table 4.18-M (4.18-I), Figure 4.31 or OMAFRA Publication 29, *Drainage Guide for Ontario*		____ mm	____ in.
28. Maximum possible flow in horizontal pipe using pipe size from Line (27), pipe slope from Line (26) (below this WASCoB) and Figure 4.31		____ m^3/s	____ ft^3/s
29. Extra horizontal pipe capacity (below this WASCoB) Line (28) – Line (24) = ____ - ____ = ____ m^3/s (____ ft^3/s)		____ m^3/s	____ ft^3/s
30. Restricting flow (identify as the smallest value of Line (21), Line (23) (if applicable; ie. an orifice plate is used) and Line (29)). If no orifice plate used, Line (23) = Line (21), do not insert 0 value		____ m^3/s	____ ft^3/s

31. Horizontal pipe flow transferred to lower WASCoB Line (30) + Line (24) = _____ + _____ = _____ m^3/s (_____ ft^3/s) If the value from Line (31) is considerably less than Line (28), consider increasing water inflow (ie. increase riser pipe size at this WASCoB location up to maximum value of Line (28)).	_____ m^3/s	_____ ft^3/s
32. Surface water transfer from Line (33) for upper WASCoB(s) Enter 0 if this is upper WASCoB	_____ m^3/s	_____ ft^3/s
33. Surface water transfer to lower WASCoB Line (32) + Line (5) (this WASCoB) = _____ + _____ = _____ m^3/s _____ ft^3/s)	_____ m^3/s	_____ ft^3/s
34. Check emergency overflow spillway type to be used	❑ Grass lined	❑ Rock lined
35. Determine emergency overflow spillway capacity from Line (33)	_____ m^3/s	_____ ft^3/s
36. Determine emergency overflow spillway notch dimension from Table 4.35-M (4.35-I) to meet capacity requirements from Line (35)		
– notch width (L)	_____ m	_____ ft
– notch depth (D)	_____ m	_____ ft
37. Actual berm height (Note: Freeboard is 10% of Line (14) to maximum of 0.15 m (6 in.)) Line (14) + freeboard + notch depth (D) (Line (36)) = _____ + _____ + _____ = _____ m _____ ft)	_____ m	_____ ft
38. Actual berm length $\frac{\text{Line (37)}}{\text{Line (9)}}$ x 200 = _______ x 200 = _______ m (_______ ft)	_____ m	_____ ft
39. Berm side slope (minimum 2:1, maximum 8:1)		_____ :1
40. Top width of berm (Note: Default width of 1.2 m (4 ft))	1.2 m	4 ft
41. Bottom width of berm Line (40) + (2 x Line (37) x Line (39)) = _______ + (2 x _______ x _______) = _______ m (_______ ft)	_____ m	_____ ft
42. Earth volume for berm from Table 4.36-M to 4.38-M (4.36-I to 4.38-I)	_____ m^3	_____ yd^3

Proceed with the design of the next (lower) Water and Sediment Control Basin. Complete a separate Water and Sediment Control Basin (WASCoB) Design Information Sheet (Multiple WASCoB System).



Notes:
1. Design berm height = pond depth = spillway elevation
   Actual berm height = design berm height + spillway depth + freeboard
2. This side view has been drawn with vertical exaggeration to present shown information more clearly.

Figure 4.32. Water and Sediment Control Basin (WASCoB)

Measuring the Runoff Storage Capacity of a Water and Sediment Control Basin

The temporary ponding area created by the construction of a WASCoB is generally triangular in shape. The approximate volume of runoff stored within the WASCoB (Figure 4.33) is determined by:

$$\text{Volume (m}^3\text{)} = \frac{\text{pond length (m) x pond width (m)}}{2} \text{ x maximum depth (m) x 0.4}$$

$$\text{Volume (ft}^3\text{)} = \frac{\text{pond length (ft) x pond width (ft)}}{2} \text{ x maximum depth (ft) x 0.4}$$

Example: A temporary ponding area is created by constructing a berm across a low draw. The berm is 1.2 m (4 ft) in height and when full the reservoir formed is 150 m long (495 ft) x 60 m wide (197 ft) at its maximum.

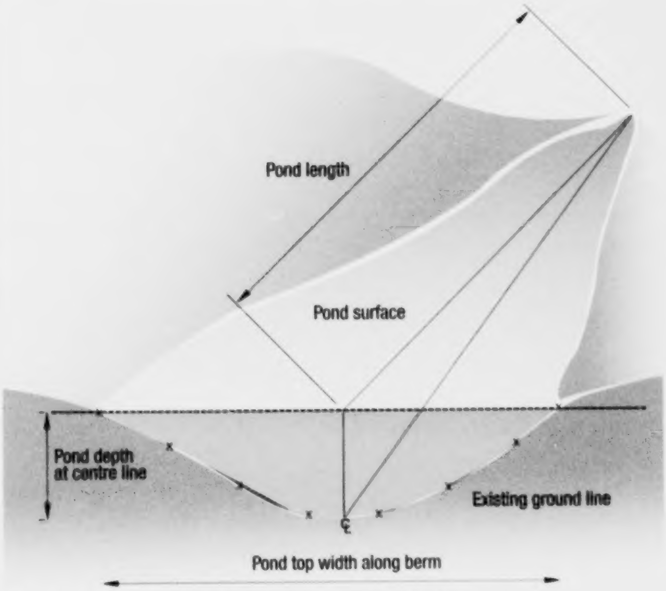
Using the equation above:

$$\text{Volume} = \frac{\text{150 m (492 ft) x 60 m (197 ft)}}{2} \text{ x 1.2 m (4 ft) x 0.4 = 2,160 m}^3 \text{ (77,540 ft}^3\text{)}$$

The storage volume may be expressed as m^3 (ft^3) or in larger ponds as acre-feet of water.

One acre-foot of water is the volume of water contained on 1 ac of land at a depth of 1 ft, which equals 43,560 ft^3. The ponding area in this example contains:

$$\frac{77{,}540 \text{ ft}^3}{43{,}560 \text{ ft}^3} = 1.78 \text{ acre-feet of water}$$



Water and sediment control basins are generally consistent in shape.
To estimate the storage volume contained in the temporary ponding area, use the following formula:

$$\text{Storage volume (m}^3\text{)} = \frac{\text{pond length (m) x pond width (m)}}{2} \text{ x maximum depth (m) x 0.4}$$

$$\text{Storage volume (ft}^3\text{)} = \frac{\text{pond length (ft) x pond width (ft)}}{2} \text{ x maximum depth (ft) x 0.4}$$

Figure 4.33. Calculating the Runoff Storage Capacity of a Water and Sediment Control Basin (WASCoB)

Notes:

1. Design berm height = pond depth = spillway elevation
   Actual berm height = design berm height + spillway depth + freeboard

2. This side view has been drawn with vertical exaggeration to present shown information more clearly.

Figure 4.32 Water and Sediment Control Basin (WASCoB)

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Example: A temporary ponding area is created by constructing a berm across a low draw. The berm is 1.2 m (4 ft) in height and when full the reservoir formed is 150 m long (495 ft) x 60 m wide (197 ft) at its maximum.

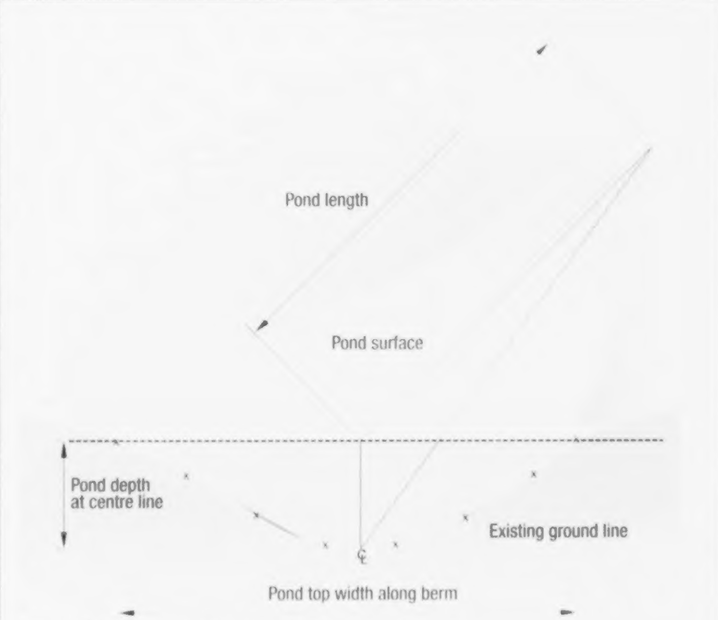
Using the equation above:

$$\text{Volume} = \frac{\text{150 m (492 ft) x 60 m (197 ft)}}{2} \text{ x 1.2 m (4 ft) x 0.4 = 2,160 m}^3 \text{ (77,540 ft}^3\text{)}$$

The storage volume may be expressed as m^3 (ft^3) or in larger ponds as acre-feet of water.

One acre-foot of water is the volume of water contained on 1 ac of land at a depth of 1 ft, which equals 43,560 ft^3. The ponding area in this example contains:

$$\frac{77{,}540 \text{ ft}^3}{43{,}560 \text{ ft}^3} = \text{1.78 acre-feet of water}$$



Water and sediment control basins are generally consistent in shape.
To estimate the storage volume contained in the temporary ponding area, use the following formula:

$$\text{Storage volume (m}^3\text{)} = \frac{\text{pond length (m) x pond width (m)}}{2} \text{ x maximum depth (m) x 0.4}$$

$$\text{Storage volume (ft}^3\text{)} = \frac{\text{pond length (ft) x pond width (ft)}}{2} \text{ x maximum depth (ft) x 0.4}$$

Figure 4.33 Calculating the Runoff Storage Capacity of a Water and Sediment Control Basin (WASCoB)

Other Design Considerations

It's essential to protect the berm in the event of overtopping. Construct an emergency spillway, consisting of a grassed or a rock lined chute spillway underlain with a proper geotextile (Figure 4.34).

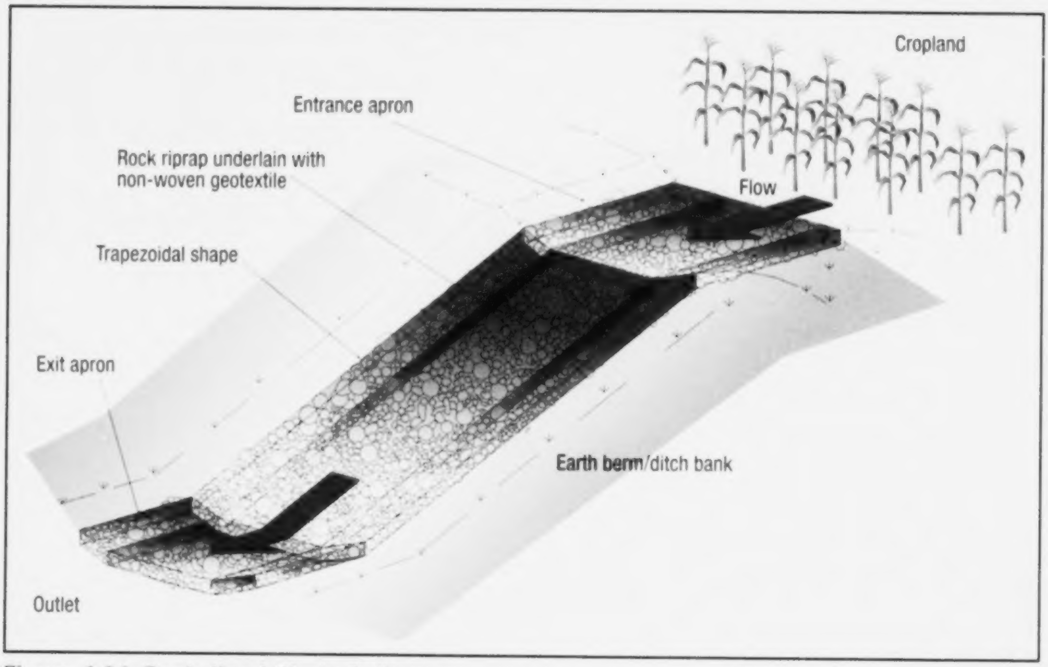


Figure 4.34. Rock-lined Chute Spillway

Determine the side slopes of the WASCoB's berm. If farm equipment is to cross, don't exceed a slope of 8 horizontal:1 vertical – considered a broad-based berm (Figure 4.29). If no equipment is expected to cross, don't exceed a slope of 3:1 in sandy soils and 2:1 in clay soils – considered a narrow-based berm (Figure 4.29). If the berm will be cropped, consider equipment widths for the inlet location. Otherwise, place the inlet as close to the berm as possible, at the lowest point of the berm profile.

Consider access required for maintenance operations such as mowing of the berm and maintenance of other structures.

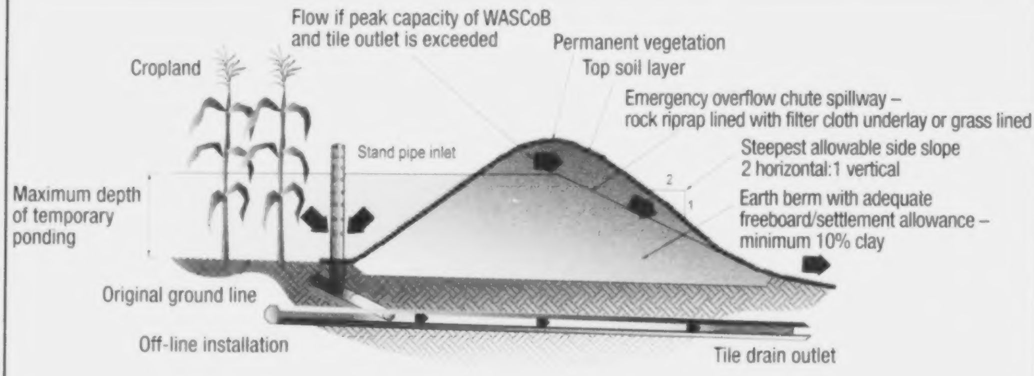
Where multiple berms are used with a common outlet tile, consider excessive water pressure or velocities. Where tile sizing can't accommodate this, install small orifice plates below the stand pipe to restrict intake rates.

WASCoB Construction

- Situate the berm to keep disruptions in existing farming practices to a minimum. Locations where knolls converge along the low draw are ideal. Never place the berm on potentially unstable soils, such as at the top edge of an existing gully. Instead, locate the berm far enough back from the crest of the gully so it won't be affected by any future settlement.
- Use earth in berm construction that's at least 10% clay and free of stones and debris. Where sufficient clay content is not available in local subsoil, truck the fill to the site. Technical expertise may be required for such decisions.
- When fill is available on site, scrape away topsoil from borrow area, stockpile and replace it following subsoil removal. Subsurface tiling is the main limiting factor in locating the borrow excavation. Consider undesirable alterations in surface drainage patterns.
- All fill may be acquired from a nearby knoll free of tile drainage. If systematic tiling exists, remove a uniform layer of 100-150 mm (4-6 in.) of subsoil over a large area.
- Aim for all fill excavation to take place in the proposed ponding area. This increases the pond storage capacity and balances the loss expected due to the triangular berm cross-section.
- Prior to berm construction, install any required subsurface tile and the stand pipe inlet. In most instances, it's recommended that stand pipe inlet be installed off line away from the main outlet tile. If the inlet is damaged or plugged with crop residue, sediment or other debris, the tile drainage system will still function properly.
- Consider and accommodate unexpected weather patterns.
- Differential settlement may occur when a tile is installed beneath a berm. This must be controlled to avert possible piping of ponded waters beneath the berm. Settlement in the trench may cause a void or an uneven crest in the berm. Figure 4.14 illustrates the proper procedure to avoid differential settlement.
- Ensure soil conditions are in a workable state prior to any excavation or construction, to avoid unnecessary soil compaction problems.

Construction Procedure

- Use a bulldozer or earth scraper for berm construction.
- Prior to constructing the berm, scrape all topsoil away from the site to assure proper adherence of the earth fill to the undisturbed subsoil.
- Place fill in well-compacted 0.15 mm (6 in.) layers. Repeated trips over the individual layers by the earth moving equipment (bulldozer or scraper) along the entire length of the berm will adequately meet compaction specifications. Always add 10% of design berm height to a maximum of 0.15 m (6 in.) for settlement and freeboard allowance.
- To ensure a uniform, level structure, plan for ongoing surveying to accompany berm construction.
- Where rodents are a potential problem, install wire mesh below the finished soil surface of the berm to prevent burrowing, especially in narrow-based berms.
- Once the berm is constructed to the desired elevation (including allowances for settlement and freeboard), push the topsoil back to completely dress the structure with at least 50 mm (2 in.) of topsoil. Also, ensure borrow areas are covered with topsoil. Then establish a proper seedbed.
- Include spillway considerations in all berms. Surveying is required to ensure proper elevations and sizing. Remember that if a number of berms are located along a single drainageway, the emergency spillways must increase in size downslope to accommodate all upslope runoff.
- Figure 4.35 illustrates a typical earthen berm cross-section.



Typical Earth Berm Cross-section

- material used to construct the berm must be a minimum 10% clay, and free of stones and debris
- topsoil should be scraped away from the berm location, stockpiled and replaced after construction is complete
- actual berm construction should consist of 0.15 m (6 in.) layers, placed and compacted progressively until the desire elevation is reached
- allowance should be given for freeboard and settlement, 10% to a maximum of 0.15 m (6 in.)
- dress berm with a minimum of 50 mm (2 in.) topsoil to facilitate vegetative growth

Figure 4.35. Typical Water and Sediment Control Basin (WASCoB) Cross-section

Maintenance

- It's recommended that a broad-based berm not be plowed. If plowing is necessary, start at the top of each side and turn the furrows upward to the crest to build up the berm.
- Leave narrow-based berms in permanent sod cover and mow annually, preferably twice. If bare areas develop, re-seed and fertilize as necessary.
- Regularly check for cracks, settlement or outlet obstructions, especially before major runoff events occur. It's much easier and more economical to alleviate potential problems at an early stage than to suffer the consequences and potentially rebuild the entire berm.
- Repairs may occasionally be required to the emergency spillway after an extremely large storm. If this repair is needed frequently, then consider undertaking major improvements to the system's capacity.
- Discourage rodents and repair any rodent damage.
- Inspect the inlet for blockage and overgrowth periodically.
- Be very careful when working around the WASCoB with machinery, particularly when operating spraying and tillage equipment adjacent to narrow-based berms with permanent sod cover.
- Conservation tillage and cropping are strongly encouraged as part of the maintenance program. As sediment settles out in the ponding area, storage volume is reduced. Relocate the deposition upslope as deemed necessary by the landowner. Use a bulldozer or a blade mounted on a tractor for this operation.

Table 4.25-M. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 65

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ha)													
		0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.003	0.006	0.009	0.015	0.022	0.030	0.046	0.060	0.075	0.090	0.104	0.119	0.134	0.148
	V_{10}	46	98	148	246	345	493	794	1058	1323	1587	1852	2116	2381	2823
	D_{10}	6.00	6.50	6.50	6.50	6.50	6.50	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.50
	Q_{25}	0.005	0.010	0.016	0.026	0.036	0.051	0.076	0.101	0.126	0.150	0.175	0.199	0.223	0.247
0.50	Q_{10}	0.003	0.006	0.009	0.016	0.022	0.031	0.046	0.061	0.076	0.091	0.106	0.121	0.136	0.150
	V_{10}	46	91	137	246	345	493	739	985	1232	1587	1852	2116	2381	2645
	D_{10}	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	7.00	7.00	7.00	7.00	7.00
	Q_{25}	0.005	0.010	0.016	0.026	0.036	0.052	0.077	0.102	0.128	0.153	0.178	0.202	0.227	0.251
1.00	Q_{10}	0.003	0.006	0.009	0.016	0.022	0.031	0.046	0.061	0.077	0.092	0.107	0.122	0.137	0.152
	V_{10}	46	91	137	228	345	493	739	985	1232	1478	1724	1971	2217	2463
	D_{10}	6.00	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
	Q_{25}	0.005	0.010	0.016	0.026	0.037	0.052	0.078	0.104	0.129	0.155	0.180	0.205	0.230	0.255
2.00	Q_{10}	0.003	0.006	0.009	0.016	0.022	0.031	0.046	0.062	0.077	0.092	0.108	0.123	0.138	0.153
	V_{10}	46	91	137	228	319	455	739	985	1232	1478	1724	1971	2217	2463
	D_{10}	6.00	6.00	6.00	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
	Q_{25}	0.005	0.011	0.016	0.026	0.037	0.053	0.079	0.104	0.130	0.156	0.182	0.207	0.233	0.258
4.00	Q_{10}	0.003	0.006	0.009	0.016	0.022	0.031	0.047	0.062	0.078	0.098	0.108	0.124	0.139	0.154
	V_{10}	46	91	137	228	319	455	683	911	1139	1478	1724	1971	2217	2463
	D_{10}	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50
	Q_{25}	0.005	0.011	0.016	0.027	0.037	0.053	0.079	0.105	0.131	0.157	0.183	0.209	0.235	0.261

Table 4.25-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 65

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	0.11	0.22	0.33	0.54	0.76	1.08	1.61	2.13	2.65	3.17	3.69	4.21	4.72	5.24
	V_{10}	1608	3480	5219	8699	12179	17398	28025	37366	46708	56049	65391	74733	84074	99701
	D_{10}	6.00	6.50	6.50	6.50	6.50	6.50	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.50
	Q_{25}	0.19	0.37	0.55	0.91	1.27	1.81	2.70	3.57	4.44	5.31	6.17	7.03	7.88	8.73
0.50	Q_{10}	0.11	0.22	0.33	0.55	0.76	1.09	1.62	2.15	2.68	3.21	3.74	4.26	4.79	5.31
	V_{10}	1608	3217	4825	8699	12179	17398	26097	34797	43496	56049	65391	74733	84074	93416
	D_{10}	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	7.00	7.00	7.00	7.00	7.00
	Q_{25}	0.19	0.37	0.56	0.92	1.29	1.83	2.73	3.62	4.51	5.39	6.27	7.14	8.02	8.88
1.00	Q_{10}	0.11	0.22	0.33	0.55	0.77	1.09	1.63	2.17	2.71	3.24	3.77	4.31	4.84	5.37
	V_{10}	1608	3217	4825	8042	12179	17398	26097	34797	43496	52195	60894	69593	78292	86992
	D_{10}	6.00	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
	Q_{25}	0.19	0.37	0.56	0.93	1.30	1.85	2.76	3.66	4.56	5.46	6.35	7.24	8.13	9.02
2.00	Q_{10}	0.11	0.22	0.33	0.55	0.77	1.10	1.64	2.18	2.73	3.27	3.80	4.34	4.88	5.41
	V_{10}	1608	3217	4825	8042	11259	16084	26097	34797	43496	52195	60894	69593	78292	86992
	D_{10}	6.00	6.00	6.00	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
	Q_{25}	0.19	0.38	0.56	0.93	1.31	1.86	2.78	3.69	4.60	5.51	6.42	7.32	8.22	9.12
4.00	Q_{10}	0.11	0.22	0.33	0.55	0.77	1.10	1.65	2.20	2.74	3.28	3.83	4.37	4.91	5.45
	V_{10}	1608	3217	4825	8042	11259	16084	24126	32168	40210	52195	60894	69593	78292	86992
	D_{10}	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.50	6.50	6.50	6.50	6.50
	Q_{25}	0.19	0.38	0.56	0.94	1.31	1.87	2.80	3.72	4.64	5.56	6.47	7.39	8.30	9.21

Table 4.26-M. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 70

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Avg Grade (%)	Parameters	Watershed Area (ha) 0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.004	0.009	0.014	0.023	0.032	0.045	0.067	0.088	0.110	0.131	0.152	0.173	0.194	0.215
	V_{10}	40	80	121	215	301	430	645	914	1142	1450	1691	1933	2174	2545
	D_{10}	3.50	3.50	3.50	3.75	3.75	3.75	4.00	4.00	4.00	4.25	4.25	4.25	4.25	4.50
	Q_{25}	0.008	0.015	0.022	0.037	0.052	0.073	0.108	0.142	0.177	0.211	0.244	0.278	0.311	0.344
0.50	Q_{10}	0.004	0.009	0.014	0.023	0.032	0.046	0.068	0.090	0.112	0.134	0.155	0.177	0.198	0.220
	V_{10}	37	80	121	201	282	430	645	860	1142	1371	1599	1828	2056	2284
	D_{10}	3.25	3.50	3.50	3.50	3.50	3.75	3.75	3.75	4.00	4.00	4.00	4.00	4.30	4.00
	Q_{25}	0.008	0.015	0.023	0.038	0.052	0.074	0.110	0.146	0.181	0.216	0.251	0.285	0.319	0.354
1.00	Q_{10}	0.005	0.009	0.014	0.023	0.032	0.046	0.069	0.091	0.114	0.136	0.158	0.180	0.202	0.224
	V_{10}	37	75	112	201	282	403	604	860	1075	1290	1505	1720	1935	2284
	D_{10}	3.25	3.25	3.25	3.50	3.50	3.50	3.50	3.75	3.75	3.75	3.75	3.75	3.75	4.00
	Q_{25}	0.008	0.015	0.023	0.038	0.053	0.075	0.112	0.148	0.184	0.220	0.256	0.291	0.326	0.362
2.00	Q_{10}	0.005	0.009	0.014	0.024	0.032	0.046	0.069	0.092	0.115	0.138	0.160	0.182	0.205	0.227
	V_{10}	37	75	112	187	262	403	604	805	1006	1208	1505	1720	1935	2150
	D_{10}	3.25	3.25	3.25	3.25	3.25	3.50	3.50	3.50	3.50	3.50	3.75	3.75	3.75	3.75
	Q_{25}	0.008	0.016	0.023	0.038	0.054	0.076	0.113	0.150	0.187	0.224	0.260	0.296	0.332	0.368
4.00	Q_{10}	0.005	0.009	0.014	0.024	0.033	0.047	0.070	0.093	0.116	0.139	0.162	0.184	0.207	0.230
	V_{10}	37	75	112	187	262	374	604	805	1006	1208	1409	1610	1812	2013
	D_{10}	3.25	3.25	3.25	3.25	3.25	3.25	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
	Q_{25}	0.008	0.016	0.023	0.039	0.054	0.077	0.115	0.152	0.189	0.227	0.264	0.301	0.338	0.370

Table 4.26-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 70

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	0.16	0.33	0.49	0.81	1.12	1.59	2.36	3.12	3.88	4.63	5.38	6.12	6.86	7.59
	V_{10}	1422	2843	4265	7593	10630	15186	24202	32269	40336	51194	59726	68259	76791	89886
	D_{10}	3.50	3.50	3.50	3.75	3.75	3.75	4.00	4.00	4.00	4.25	4.25	4.25	4.25	4.50
	Q_{25}	0.27	0.53	0.79	1.31	1.82	2.57	3.81	5.03	6.24	7.44	8.63	9.81	10.99	12.16
0.50	Q_{10}	0.17	0.33	0.49	0.81	1.13	1.61	2.40	3.18	3.95	4.72	5.48	6.25	7.00	7.76
	V_{10}	1323	2843	4265	7109	9952	15186	22778	30371	40336	48403	56471	64538	72605	80672
	D_{10}	3.25	3.50	3.50	3.50	3.50	3.75	3.75	3.75	4.00	4.00	4.00	4.00	4.30	4.00
	Q_{25}	0.27	0.54	0.80	1.33	1.85	2.62	3.89	5.14	6.39	7.62	8.85	10.07	11.28	12.49
1.00	Q_{10}	0.17	0.33	0.50	0.82	1.15	1.63	2.43	3.22	4.01	4.79	5.58	6.35	7.13	7.90
	V_{10}	1323	2646	3968	7109	9952	14217	21326	30371	37964	45557	53150	60743	68335	80672
	D_{10}	3.25	3.25	3.25	3.50	3.50	3.50	3.50	3.75	3.75	3.75	3.75	3.75	3.75	4.00
	Q_{25}	0.27	0.54	0.81	1.34	1.87	2.66	3.95	5.23	6.51	7.77	9.03	10.29	11.53	12.77
2.00	Q_{10}	0.17	0.33	0.50	0.83	1.15	1.64	2.45	3.26	4.06	4.86	5.65	6.44	7.23	8.02
	V_{10}	1323	2646	3968	6614	9259	14217	21326	28434	35543	42651	53150	60743	68335	75928
	D_{10}	3.25	3.25	3.25	3.25	3.25	3.50	3.50	3.50	3.50	3.50	3.75	3.75	3.75	3.75
	Q_{25}	0.28	0.55	0.82	1.36	1.89	2.69	4.00	5.31	6.61	7.90	9.19	10.47	11.74	13.01
4.00	Q_{10}	0.17	0.33	0.50	00.83	1.16	1.65	2.47	3.29	4.10	4.91	5.71	6.51	7.32	8.12
	V_{10}	1323	2646	3966	6614	9259	13228	21326	28434	35543	42651	49760	56868	63977	71085
	D_{10}	3.25	3.25	3.25	3.25	3.25	3.25	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
	Q_{25}	0.28	0.55	0.82	1.37	1.91	2.71	4.05	5.37	6.69	8.01	9.32	10.62	11.92	13.22

Table 4.27-M. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 75

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Avg Grade (%)	Parameters	Watershed Area (ha)													
		0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.007	0.014	0.021	0.034	0.048	0.067	0.100	0.131	0.162	0.193	0.224	0.254	0.284	0.314
	V_{10}	33	69	108	189	265	394	616	853	1105	1326	1602	1830	2128	2364
	D_{10}	1.80	1.90	2.00	2.10	2.10	2.20	2.30	2.40	2.50	2.50	2.60	2.60	2.70	2.70
	Q_{25}	0.011	0.022	0.033	0.054	0.074	0.105	0.154	0.203	0.251	0.298	0.344	0.390	0.436	0.482
0.50	Q_{10}	0.007	0.014	0.022	0.035	0.049	0.069	0.102	0.135	0.167	0.199	0.231	0.263	0.294	0.325
	V_{10}	31	65	103	172	253	378	567	789	1026	1232	1493	1706	1919	2211
	D_{10}	1.70	1.80	1.90	1.90	2.00	2.10	2.10	2.20	2.30	2.30	2.40	2.40	2.40	2.50
	Q_{25}	0.012	0.023	0.034	0.055	0.076	0.108	0.159	0.210	0.259	0.308	0.357	0.405	0.453	0.501
1.00	Q_{10}	0.007	0.014	0.022	0.036	0.050	0.070	0.104	0.138	0.172	0.205	0.238	0.270	0.302	0.335
	V_{10}	31	62	98	164	241	344	542	756	945	1134	1381	1578	1775	2053
	D_{10}	1.70	1.70	1.80	1.80	1.90	1.90	2.00	2.10	2.10	2.10	2.20	2.20	2.20	2.30
	Q_{25}	0.012	0.023	0.034	0.056	0.078	0.110	0.163	0.215	0.267	0.318	0.369	0.419	0.469	0.518
2.00	Q_{10}	0.007	0.015	0.022	0.036	0.050	0.072	0.106	0.141	0.175	0.209	0.243	0.276	0.310	0.343
	V_{10}	29	62	93	164	229	327	517	689	904	1084	1265	1512	1701	1890
	D_{10}	1.60	1.70	1.70	1.80	1.80	1.80	1.90	1.90	2.00	2.00	2.00	2.10	2.10	2.10
	Q_{25}	0.012	0.023	0.035	0.057	0.079	0.112	0.167	0.220	0.274	0.326	0.378	0.431	0.482	0.534
4.00	Q_{10}	0.007	0.015	0.022	0.036	0.051	0.072	0.108	0.143	0.178	0.213	0.247	0.282	0.316	0.350
	V_{10}	29	54	93	155	217	327	491	655	861	1034	1206	1378	1627	1807
	D_{10}	1.60	1.60	1.70	1.70	1.70	1.80	1.80	1.80	1.90	1.90	1.90	1.90	2.00	2.00
	Q_{25}	0.012	0.024	0.035	0.058	0.080	0.114	0.170	0.225	0.279	0.334	0.387	0.441	0.494	0.547

Table 4.27-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 75

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	0.25	0.50	0.74	1.22	1.69	2.38	3.52	4.64	5.74	6.83	7.91	8.98	10.04	11.10
	V_{10}	1156	2434	3830	6676	9347	13931	21750	30122	39036	46843	56559	64639	75141	83489
	D_{10}	1.80	1.90	2.00	2.10	2.10	2.20	2.30	2.40	2.50	2.50	2.60	2.60	2.70	2.70
	Q_{25}	0.40	0.78	1.16	1.90	2.63	3.70	5.45	7.16	8.85	10.51	12.16	13.79	15.40	17.01
0.50	Q_{10}	0.26	0.51	0.76	1.24	1.73	2.44	3.61	4.77	5.91	7.04	8.16	9.28	10.38	11.48
	V_{10}	1095	2312	3651	6084	8936	13353	20029	27861	36250	43500	52714	60245	67775	78072
	D_{10}	1.70	1.80	1.90	1.90	2.00	2.10	2.10	2.20	2.30	2.30	2.40	2.40	2.40	2.50
	Q_{25}	0.41	0.80	1.19	1.95	2.70	3.80	5.62	7.40	9.15	10.89	12.61	14.32	16.01	17.69
1.00	Q_{10}	0.26	0.51	0.77	1.26	1.76	2.49	3.69	4.88	6.06	7.23	8.39	9.54	10.68	11.82
	V_{10}	1095	2189	3469	5781	8518	12169	19148	26705	33381	40058	48757	55723	62688	72500
	D_{10}	1.70	1.70	1.80	1.80	1.90	1.90	2.00	2.10	2.10	2.10	2.20	2.20	2.20	2.30
	Q_{25}	0.41	0.81	1.21	1.99	2.75	3.89	5.76	7.61	9.43	11.23	13.02	14.79	16.56	18.31
2.00	Q_{10}	0.26	0.52	0.77	1.28	1.78	2.53	3.76	4.98	6.19	7.39	8.58	9.76	10.94	12.12
	V_{10}	1032	2189	3284	5781	8093	11562	18253	24337	31913	38296	44679	53410	60086	66763
	D_{10}	1.60	1.70	1.70	1.80	1.80	1.80	1.90	1.90	2.00	2.00	2.00	2.10	2.10	2.10
	Q_{25}	0.41	0.82	1.22	2.02	2.80	3.97	5.89	7.79	9.67	11.53	13.37	15.21	17.04	18.85
4.00	Q_{10}	0.26	0.52	0.78	1.29	1.80	2.56	3.82	5.06	6.29	7.52	8.74	9.96	11.17	12.37
	V_{10}	1032	2063	3284	5463	7662	11562	17343	23124	30422	36506	42590	48675	57444	63827
	D_{10}	1.60	1.60	1.70	1.70	1.70	1.80	1.80	1.80	1.90	1.90	1.90	1.90	2.00	2.00
	Q_{25}	0.42	0.83	1.24	2.04	2.84	4.04	6.00	7.94	9.87	11.78	13.68	15.57	17.46	19.33

Table 4.28-M. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 80

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ha)													
		0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.012	0.022	0.033	0.054	0.074	0.103	0.151	0.198	0.244	0.289	0.334	0.377	0.421	0.464
	V_{10}	29	63	99	178	258	381	608	835	1073	1323	1584	1856	2139	2432
	D_{10}	0.95	1.05	1.10	1.20	1.25	1.30	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
	Q_{25}	0.017	0.033	0.049	0.080	0.110	0.153	0.223	0.291	0.358	0.424	0.489	0.552	0.616	0.678
0.50	Q_{10}	0.012	0.023	0.034	0.056	0.076	0.108	0.158	0.207	0.255	0.303	0.350	0.396	0.442	0.488
	V_{10}	28	58	91	158	231	356	451	762	983	1216	1461	1670	1932	2147
	D_{10}	0.90	0.95	1.00	1.05	1.10	1.20	1.25	1.30	1.35	1.40	1.45	1.45	1.50	1.50
	Q_{25}	0.018	0.034	0.051	0.083	0.114	0.159	0.234	0.306	0.377	0.446	0.515	0.583	0.650	0.717
1.00	Q_{10}	0.012	0.024	0.035	0.057	0.079	0.111	0.163	0.215	0.266	0.315	0.365	0.420	0.462	0.510
	V_{10}	26	55	87	151	212	316	514	711	889	1105	1333	1524	1770	1966
	D_{10}	0.85	0.90	0.95	1.00	1.00	1.05	1.15	1.20	1.20	1.25	1.30	1.30	1.35	1.35
	Q_{25}	0.018	0.035	0.052	0.086	0.118	0.166	0.243	0.319	0.394	0.467	0.540	0.612	0.683	0.753
2.00	Q_{10}	0.012	0.024	0.036	0.058	0.081	0.114	0.168	0.222	0.275	0.327	0.378	0.430	0.481	0.531
	V_{10}	25	52	82	138	202	302	475	633	824	1028	1200	1423	1601	1779
	D_{10}	0.80	0.85	0.90	0.90	0.95	1.00	1.05	1.05	1.10	1.15	1.15	1.20	1.20	1.20
	Q_{25}	0.018	0.036	0.054	0.088	0.121	0.171	0.252	0.331	0.409	0.486	0.563	0.638	0.713	0.787
4.00	Q_{10}	0.012	0.024	0.036	0.060	0.083	0.117	0.173	0.228	0.283	0.337	0.391	0.444	0.497	0.550
	V_{10}	25	49	78	130	193	275	434	606	757	949	1107	1266	1484	1649
	D_{10}	0.80	0.80	0.85	0.85	0.90	0.90	0.95	1.00	1.00	1.05	1.05	1.05	1.10	1.10
	Q_{25}	0.019	0.037	0.055	0.090	0.122	0.176	0.260	0.342	0.423	0.504	0.583	0.662	0.741	0.819

Table 4.28-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 80

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	0.41	0.79	1.17	1.90	2.61	3.65	5.35	7.00	8.62	10.21	11.78	13.33	14.86	16.38
	V_{10}	1021	2235	3493	6281	9108	13453	21479	29487	37905	46727	55944	65549	75536	85899
	D_{10}	0.95	1.05	1.10	1.20	1.25	1.30	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
	Q_{25}	0.61	1.18	1.74	2.82	3.87	5.40	7.88	10.29	12.65	14.97	17.26	19.51	21.74	23.94
0.50	Q_{10}	0.42	0.81	1.20	1.96	2.70	3.80	5.57	7.31	9.01	10.70	12.36	14.00	15.62	17.23
	V_{10}	972	2042	3209	5587	8151	12562	19516	26906	34723	42957	51602	58973	68230	75811
	D_{10}	0.90	0.95	1.00	1.05	1.10	1.20	1.25	1.30	1.35	1.40	1.45	1.45	1.50	1.50
	Q_{25}	0.63	1.22	1.80	2.92	4.02	5.63	8.25	10.80	13.30	15.76	18.19	20.58	22.96	25.31
1.00	Q_{10}	0.42	0.83	1.23	2.02	2.79	3.92	5.77	7.59	9.38	11.14	12.89	14.82	16.33	18.03
	V_{10}	921	1943	3063	5346	7488	11174	18160	25124	31405	39032	47086	53812	62501	69445
	D_{10}	0.85	0.90	0.95	1.00	1.00	1.05	1.15	1.20	1.20	1.25	1.30	1.30	1.35	1.35
	Q_{25}	0.64	1.25	1.85	3.02	4.16	5.85	8.59	11.27	13.90	16.50	19.06	21.60	24.11	26.60
2.00	Q_{10}	0.43	0.85	1.26	2.06	2.86	4.03	5.95	7.84	9.71	11.55	13.37	15.18	16.98	8.76
	V_{10}	870	1843	2915	4858	7148	10697	16761	22349	29110	36320	42373	50248	56530	62811
	D_{10}	0.80	0.85	0.90	0.90	0.95	1.00	1.05	1.05	1.10	1.15	1.15	1.20	1.20	1.20
	Q_{25}	0.65	1.28	1.89	3.10	4.29	6.04	8.89	11.69	14.45	17.17	19.87	22.53	25.181	27.80
4.00	Q_{10}	0.44	0.86	1.28	2.11	2.92	4.13	6.11	8.07	10.00	11.91	13.81	15.69	17.56	19.42
	V_{10}	870	1740	2764	4607	6802	9717	15316	21393	26742	33523	39110	44697	52399	58221
	D_{10}	0.80	0.80	0.85	0.85	0.90	0.90	0.95	1.00	1.00	1.05	1.05	1.05	1.10	1.10
	Q_{25}	0.66	1.30	1.93	3.1'	4.40	6.21	9.17	12.08	14.95	17.79	20.60	23.39	26.16	28.91

Table 4.29-M. Peak Flows, Storm Durations and S'orm Volumes for a Watershed, Runoff Curve Number 85

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ha)													
		0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.019	0.037	0.054	0.086	0.117	0.162	0.234	0.299	0.372	0.439	0.504	0.658	0.631	0.693
	V_{10}	28	60	96	181	268	403	632	880	1146	1429	1727	1974	2298	2636
	D_{10}	0.50	0.55	0.60	0.70	0.75	0.80	0.85	0.90	0.95	1.00	1.05	1.05	1.10	1.15
	Q_{25}	0.027	0.052	0.076	0.121	0.164	0.227	0.328	0.425	0.519	0.602	0.701	0.790	0.877	0.693
0.50	Q_{10}	0.020	0.038	0.056	0.090	0.124	0.172	0.249	0.324	0.398	0.469	0.539	0.609	0.677	0.744
	V_{10}	25	55	90	160	240	363	575	805	1006	1265	1541	1761	2063	2292
	D_{10}	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.80	0.85	0.90	0.90	0.95	0.95
	Q_{25}	0.029	0.055	0.080	0.128	0.174	0.242	0.350	0.454	0.556	0.656	0.754	0.850	0.944	1.038
1.00	Q_{10}	0.021	0.040	0.059	0.095	0.130	0.181	0.264	0.344	0.422	0.499	0.574	0.649	0.723	0.795
	V_{10}	23	50	83	149	209	321	515	726	907	1149	1341	1610	1812	2013
	D_{10}	0.40	0.45	0.50	0.55	0.55	0.60	0.65	0.70	0.70	0.75	0.75	0.80	0.80	0.80
	Q_{25}	0.030	0.057	0.084	0.134	0.184	0.256	0.372	0.483	0.593	0.700	0.806	0.909	1.011	1.112
2.00	Q_{10}	0.022	0.042	0.061	0.099	0.136	0.190	0.278	0.363	0.446	0.528	0.608	0.688	0.767	0.845
	V_{10}	23	46	76	126	193	299	448	642	802	1027	1198	1452	1633	1815
	D_{10}	0.40	0.40	0.45	0.45	0.50	0.55	0.55	0.60	0.60	0.65	0.65	0.70	0.70	0.70
	Q_{25}	0.030	0.059	0.087	0.141	0.193	0.269	0.392	0.512	0.629	0.743	0.856	0.967	1.077	1.186
4.00	Q_{10}	0.022	0.043	0.063	0.103	0.142	0.198	0.290	0.380	0.468	0.555	0.641	0.725	0.809	0.892
	V_{10}	20	46	68	126	176	252	414	598	747	896	1123	1283	1444	1604
	D_{10}	0.35	0.40	0.40	0.45	0.45	0.45	0.50	0.55	0.55	0.55	0.60	0.60	0.60	0.60
	Q_{25}	0.031	0.061	0.090	0.147	0.202	0.282	0.412	0.538	0.663	0.785	0.905	1.024	1.141	1.257

Table 4.29-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 85

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	0.68	1.30	1.90	3.04	4.14	5.73	8.28	10.75	13.15	15.49	17.79	20.05	22.28	24.48
	V_{10}	975	2110	3399	6409	9469	14219	22338	31098	40475	50451	61005	69720	81137	93093
	D_{10}	0.50	0.55	0.60	0.70	0.75	0.80	0.85	0.90	0.95	1.00	1.05	1.05	1.10	1.15
	Q_{25}	0.97	1.84	2.67	4.27	5.80	8.03	11.58	15.00	18.33	21.56	24.76	27.89	30.98	34.02
0.50	Q_{10}	0.71	1.36	1.99	3.20	4.37	6.07	8.81	11.46	14.04	16.57	19.05	21.50	23.91	26.29
	V_{10}	891	1949	3166	5666	8460	12817	20292	28438	35547	44677	54421	62196	72856	80951
	D_{10}	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.80	0.85	0.90	0.90	0.95	0.95
	Q_{25}	1.01	1.93	2.82	4.52	6.16	8.54	12.36	16.05	19.65	23.16	26.61	30.01	33.35	36.66
1.00	Q_{10}	0.73	1.42	2.08	3.36	4.60	6.40	9.32	12.15	14.91	17.63	20.29	22.92	25.52	28.08
	V_{10}	804	1782	2924	5276	7387	11332	18129	25635	32043	40583	47347	56876	63985	71095
	D_{10}	0.40	0.45	0.50	0.55	0.55	0.60	0.65	0.70	0.70	0.75	0.75	0.80	0.80	0.80
	Q_{25}	1.05	2.02	2.95	4.75	6.50	9.04	13.13	17.06	20.94	24.73	28.45	32.11	35.72	39.29
2.00	Q_{10}	0.76	1.47	2.16	3.50	4.80	6.71	9.80	12.81	15.75	18.64	21.49	24.30	27.08	29.83
	V_{10}	804	1607	2672	4454	6822	10552	15828	22663	28329	36257	42300	51269	57678	64086
	D_{10}	0.40	0.40	0.45	0.45	0.50	0.55	0.55	0.60	0.60	0.65	0.65	0.70	0.70	0.70
	Q_{25}	1.08	2.10	3.08	4.97	6.82	9.51	13.85	18.08	22.20	26.25	30.24	34.16	38.05	41.89
4.00	Q_{10}	0.78	1.51	2.23	3.63	5.00	7.00	10.25	13.42	16.54	19.61	22.63	25.62	28.58	31.50
	V_{10}	713	1607	2411	4454	6236	8908	14618	21105	26381	31657	39660	45326	50992	56658
	D_{10}	0.35	0.40	0.40	0.45	0.45	0.45	0.50	0.55	0.55	0.55	0.60	0.60	0.60	0.60
	Q_{25}	1.11	2.17	3.19	5.18	7.12	9.95	14.55	19.01	23.40	27.71	31.95	36.15	40.30	44.40

Table 4.30-M. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 90

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ha)													
		0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.034	0.063	0.091	0.142	0.192	0.262	0.373	0.479	0.581	0.680	0.777	0.872	0.964	1.056
	V_{10}	28	64	108	198	301	462	738	1041	1031	1645	1919	2299	2586	3002
	D_{10}	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.60	0.65	0.65	0.70	0.70	0.75
	Q_{25}	0.045	0.084	0.121	0.189	0.254	0.347	0.493	0.633	0.767	0.897	1.025	1.149	1.271	1.391
0.50	Q_{10}	0.036	0.068	0.098	0.155	0.208	0.286	0.408	0.524	0.637	0.747	0.854	0.958	1.061	1.163
	V_{10}	28	57	97	181	253	397	645	924	1154	1476	1721	2082	2343	2603
	D_{10}	0.25	0.25	0.30	0.35	0.35	0.40	0.45	0.50	0.50	0.55	0.55	0.60	0.60	0.60
	Q_{25}	0.049	0.091	0.130	0.205	0.276	0.378	0.539	0.693	0.842	0.986	1.127	1.265	1.401	1.534
1.00	Q_{10}	0.038	0.067	0.105	0.166	0.225	0.309	0.443	0.571	0.695	0.815	0.933	1.049	1.163	1.274
	V_{10}	24	57	85	162	227	362	542	794	992	1291	1506	1847	2078	2309
	D_{10}	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.40	0.45	0.45	0.50	0.50	0.50
	Q_{25}	0.052	0.097	0.140	0.221	0.299	0.410	0.587	0.756	0.920	1.079	1.235	1.387	1.536	1.684
2.00	Q_{10}	0.041	0.078	0.112	0.179	0.242	0.333	0.479	0.619	0.754	0.886	1.015	1.142	1.267	1.389
	V_{10}	24	48	72	142	198	324	486	723	904	1085	1389	1588	1786	1985
	D_{10}	0.20	0.20	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.35	0.40	0.40	0.40	0.40
	Q_{25}	0.055	0.107	0.150	0.238	0.322	0.443	0.636	0.820	1.000	1.175	1.344	1.513	1.678	1.840
4.00	Q_{10}	0.043	0.082	0.119	0.190	0.258	0.357	0.514	0.667	0.814	0.958	1.098	1.237	1.374	1.508
	V_{10}	19	48	72	119	198	283	425	648	810	972	1266	1446	1627	1808
	D_{10}	0.15	0.20	0.20	0.20	0.25	0.25	0.25	0.30	0.30	0.30	0.35	0.35	0.35	0.35
	Q_{25}	0.058	0.110	0.159	0.254	0.345	0.476	0.685	0.885	1.081	1.272	1.458	1.641	1.822	2.000

Table 4.30-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 90

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

		Watershed													
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	1.20	2.24	3.21	5.04	6.78	9.26	13.18	16.92	20.53	24.03	27.44	30.78	34.06	37.28
	V_{10}	1000	2288	3831	7009	10635	16308	26055	36770	45963	58078	67758	81186	91335	106002
	D_{10}	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.60	0.65	0.65	0.70	0.70	0.75
	Q_{25}	1.60	2.97	4.26	6.68	8.97	12.24	17.42	22.34	27.09	31.69	36.19	40.58	44.89	49.12
0.50	Q_{10}	1.29	2.41	3.46	5.46	7.36	10.09	14.40	18.52	22.50	26.37	30.15	33.84	37.48	41.06
	V_{10}	1000	2001	3432	6385	8940	14018	22790	32616	40770	52109	60794	73541	82733	91926
	D_{10}	0.25	0.25	0.30	0.35	0.35	0.40	0.45	0.50	0.50	0.55	0.55	0.60	0.60	0.60
	Q_{25}	1.72	3.20	4.60	7.24	9.76	13.36	19.05	24.49	29.74	34.83	39.81	44.69	49.47	54.18
1.00	Q_{10}	1.37	2.57	3.72	5.88	7.95	10.92	15.64	20.17	24.53	28.80	32.96	37.03	41.06	45.01
	V_{10}	844	2001	3001	5720	8008	12771	19156	28035	35044	45580	53177	65232	73386	81540
	D_{10}	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.40	0.45	0.45	0.50	0.50	0.50
	Q_{25}	1.83	3.43	4.95	7.82	10.56	14.49	20.74	26.71	32.49	38.10	43.60	48.98	54.26	59.48
2.00	Q_{10}	1.45	2.74	3.96	6.31	8.54	11.77	16.91	21.85	26.63	31.28	35.85	40.34	44.74	49.07
	V_{10}	844	1688	2532	5002	7003	11439	17159	25542	31927	38313	49062	56071	63080	70089
	D_{10}	0.20	0.20	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.35	0.40	0.40	0.40	0.40
	Q_{25}	1.94	3.66	5.30	8.40	11.38	15.63	22.47	28.97	35.32	41.48	47.48	53.42	59.25	64.98
4.00	Q_{10}	1.52	2.89	4.21	6.72	9.11	12.61	18.17	23.54	28.75	33.82	38.78	43.69	48.52	53.27
	V_{10}	670	1688	2532	4219	7003	10004	15006	22879	28598	34318	44698	51084	57469	63855
	D_{10}	0.15	0.20	0.20	0.20	0.25	0.25	0.25	0.30	0.30	0.30	0.35	0.35	0.35	0.35
	Q_{25}	2.05	3.88	5.62	8.98	12.17	16.80	24.20	31.27	38.19	44.93	51.50	57.94	64.34	70.64

Table 4.31-M. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 95

Q_{10} – watershed peak flow for a 10-year storm (m^3/s)
V_{10} – total storm volume in a 10-year storm (m^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (m^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ha)													
		0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
0.25	Q_{10}	0.065	0.117	0.164	0.251	0.332	0.446	0.623	0.790	0.948	1.101	1.248	1.392	1.533	1.665
	V_{10}	39	77	137	259	362	572	858	1242	1667	2000	2334	2553	3191	3546
	D_{10}	0.15	0.15	0.20	0.25	0.25	0.30	0.30	0.35	0.40	0.40	0.40	0.45	0.45	0.45
	Q_{25}	0.081	0.145	0.204	0.311	0.412	0.554	0.773	0.980	1.177	1.367	1.550	1.730	1.904	2.074
0.50	Q_{10}	0.072	0.131	0.184	0.282	0.374	0.502	0.704	0.892	1.073	1.246	1.415	1.580	1.740	1.896
	V_{10}	30	77	116	228	320	518	776	1144	1430	1716	2174	2485	2796	3334
	D_{10}	0.10	0.15	0.15	0.20	0.20	0.25	0.25	0.30	0.30	0.30	0.35	0.35	0.35	0.40
	Q_{25}	0.090	0.162	0.228	0.349	0.463	0.623	0.873	1.107	1.331	1.546	1.756	1.960	2.159	2.354
1.00	Q_{10}	0.081	0.145	0.205	0.316	0.418	0.564	0.792	1.005	1.211	1.408	1.598	1.785	1.968	2.147
	V_{10}	30	60	116	193	271	457	685	1035	1294	1552	1811	2287	2573	2859
	D_{10}	0.10	0.10	0.15	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.30	0.30	0.30
	Q_{25}	0.100	0.180	0.253	0.391	0.518	0.699	0.981	1.246	1.501	1.745	1.981	2.214	2.441	2.663
2.00	Q_{10}	0.088	0.161	0.228	0.349	0.467	0.632	0.886	1.129	1.361	1.584	1.799	2.010	2.218	2.422
	V_{10}	30	60	91	193	271	387	580	913	1142	1369	1598	2070	2329	2588
	D_{10}	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.25	0.25	0.25
	Q_{25}	0.109	0.199	0.282	0.433	0.578	0.782	1.096	1.398	1.686	1.962	2.228	2.491	2.749	3.002
4.00	Q_{10}	0.096	0.176	0.251	0.390	0.519	0.699	0.990	1.264	1.523	1.772	2.016	2.257	2.492	2.722
	V_{10}	19	60	91	151	212	387	580	774	967	1160	1598	1827	2055	2283
	D_{10}	0.05	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20
	Q_{25}	0.119	0.218	0.311	0.482	0.642	0.865	1.226	1.564	1.885	2.193	2.497	2.796	3.087	3.372

Table 4.31-I. Peak Flows, Storm Durations and Storm Volumes for a Watershed, Runoff Curve Number 95

Q_{10} – watershed peak flow for a 10-year storm (ft^3/s)
V_{10} – total storm volume in a 10-year storm (ft^3)
D_{10} – 10-year storm duration (hours)
Q_{25} – peak flow for a 25-year storm (ft^3/s)

Watershed															
Avg Grade (%)	Parameters	Area (ac)													
		1	2	3	5	7	10	15	20	25	30	35	40	45	50
0.25	Q_{10}	2.31	4.13	5.81	8.87	11.74	15.76	22.01	27.89	33.47	38.88	44.09	49.17	54.13	58.97
	V_{10}	1366	2732	4838	9138	12793	20195	30292	43879	58868	70641	82415	00169	12690	125211
	D_{10}	0.15	0.15	0.20	0.25	0.25	0.30	0.30	0.35	0.40	0.40	0.40	0.45	0.45	0.45
	Q_{25}	2.86	5.11	7.19	11.00	14.56	19.55	27.30	34.62	41.56	48.27	54.74	61.08	67.25	73.26
0.50	Q_{10}	2.56	4.62	6.50	9.96	13.21	17.74	24.86	31.52	37.91	44.02	49.98	55.79	61.43	66.94
	V_{10}	1069	2732	4097	8064	11289	18276	27414	40389	50487	60584	76789	87759	98729	117735
	D_{10}	0.10	0.15	0.15	0.20	0.20	0.25	0.25	0.30	0.30	0.30	0.35	0.35	0.35	0.40
	Q_{25}	3.17	5.72	8.04	12.34	16.36	21.99	30.82	39.09	47.02	54.60	62.03	69.23	76.24	83.12
1.00	Q_{10}	2.85	5.13	7.23	11.16	14.78	19.93	27.97	35.49	42.76	49.73	56.44	63.04	69.51	75.82
	V_{10}	1069	2139	4097	6829	9561	16128	24191	36552	45689	54827	63965	80779	90876	100973
	D_{10}	0.10	0.10	0.15	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.30	0.30	0.30
	Q_{25}	3.52	6.34	8.94	13.81	18.29	24.68	34.64	43.99	53.00	61.64	69.96	78.19	86.21	94.04
2.00	Q_{10}	3.11	5.69	8.05	12.35	16.49	22.31	31.29	39.86	48.07	55.94	63.54	70.98	78.34	85.52
	V_{10}	1069	2139	3208	6829	9561	13658	20487	32255	40319	48363	56446	73103	82241	91379
	D_{10}	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.25	0.25	0.25
	Q_{25}	3.84	7.04	9.95	15.28	20.41	27.61	38.72	49.37	59.54	69.29	78.70	87.98	97.09	106.00
4.00	Q_{10}	3.41	6.22	8.88	13.79	18.33	24.70	34.98	44.63	53.80	62.59	71.21	79.72	88.02	96.14
	V_{10}	681	2139	3208	5347	7485	13658	20487	27317	34146	40975	56446	64510	72574	80638
	D_{10}	0.05	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20
	Q_{25}	4.21	7.69	10.97	17.04	22.66	30.56	43.29	55.23	66.57	77.45	88.19	98.74	109.02	119.07

Table 4.32-M. Determination of Expected Average Annual Soil Loss

Factors Affecting Soil Loss	Expected Soil Loss (tonnes/ha/yr)					
Slope and Crop	Very Fine Sand, Loamy Very Fine Sand	Very Fine Sandy Loam, Silt Loam, Loam	Silty Clay Loam, Fine Sandy Loam, Clay Loam, Loamy Fine Sand, Sandy Clay Loam	Fine Sand, Sandy Loam, Silty Clay	Loamy Sand, Sand, Clay	Heavy Clay
Slope: 0% to 2% average slope						
Continuous Soybeans						
- fall plow	7.8	5.7	3.4	2.5	1.8	0.6
- no-till	4.1	3.0	1.8	1.3	0.9	0.3
Continuous Corn						
- fall plow	5.7	4.1	2.5	1.8	1.3	0.5
- spring plow	5.3	3.8	2.3	1.7	1.2	0.4
- fall chisel	4.3	3.1	1.9	1.4	1.0	0.4
- no-till	1.4	1.0	0.6	0.5	0.3	0.1
Rotational Corn (corn-soybeans-small grains) – conventional till	4.7	3.4	2.0	1.5	1.1	0.4
Rotational Corn (corn-soybeans-small grains) – no-till	1.3	0.9	0.6	0.4	0.3	0.1
Tobacco	5.0	3.6	2.2	1.6	1.1	–
Seasonal Horticultural Crops	6.4	4.6	2.8	2.1	1.5	0.5
Orchard	1.4	1.0	0.6	0.5	0.3	0.1
Hay	0.7	0.5	0.3	0.2	0.2	0.1
Permanent Pasture	0.4	0.3	0.2	0.1	0.1	0.0
Slope: >2% to 5% average slope						
Continuous Soybeans						
- fall plow	21.3	15.4	9.2	6.8	4.8	1.8
- no-till	11.2	8.1	4.9	3.6	2.6	0.9
Continuous Corn						
- fall plow	15.5	11.2	6.7	5.0	3.5	1.3
- spring plow	14.4	10.4	6.2	4.6	3.3	1.2
- fall chisel	11.6	8.4	5.0	3.7	2.6	1.0
- no-till	3.9	2.8	1.7	1.2	0.9	0.3
Rotational Corn (corn-soybeans-small grains) – conventional till	12.8	9.2	5.5	4.1	2.9	1.1
Rotational Corn (corn-soybeans-small grains) – no-till	3.5	2.5	1.5	1.1	0.8	0.3
Tobacco	13.6	9.8	5.9	4.3	3.1	–
Seasonal Horticultural Crops	17.5	12.6	7.6	5.6	4.0	1.4
Orchard	3.9	2.8	1.7	1.2	0.9	0.3
Hay	1.9	1.4	0.8	0.6	0.4	0.2
Permanent Pasture	1.2	0.8	0.5	0.4	0.3	0.1

Table 4.32-M. Determination of Expected Average Annual Soil Loss

Factors Affecting Soil Loss	Expected Soil Loss (tonnes/ha/yr)					
Slope and Crop	Very Fine Sand, Loamy Very Fine Sand	Very Fine Sandy Loam, Silt Loam, Loam	Silty Clay Loam, Fine Sandy Loam, Clay Loam, Loamy Fine Sand, Sandy Clay Loam	Fine Sand, Sandy Loam, Silty Clay	Loamy Sand, Sand, Clay	Heavy Clay
Slope: >5% to 9% average slope						
Continuous Soybeans						
- fall plow	**53.8**	**38.8**	**23.3**	**17.2**	**12.2**	**4.4**
- no-till	**28.4**	**20.5**	**12.3**	**9.1**	**6.4**	**2.3**
Continuous Corn						
- fall plow	39.1	28.2	16.9	12.5	8.9	3.2
- spring plow	36.2	26.1	15.7	11.6	8.2	3.0
- fall chisel	29.3	21.2	12.7	9.4	6.7	2.4
- no-till	9.8	7.1	4.2	3.1	2.2	0.8
Rotational Corn (corn-soybeans-small grains) – conventional till	**32.3**	**23.3**	**14.0**	**10.3**	**7.3**	**2.7**
Rotational Corn (corn-soybeans-small grains) – no-till	8.8	6.3	3.9	2.8	2.0	0.7
Tobacco	**34.2**	**24.7**	**14.8**	**10.9**	**7.8**	**–**
Seasonal Horticultural Crops	44.0	31.8	19.1	14.1	10.0	3.6
Orchard	**9.8**	**7.1**	**4.2**	**3.1**	**2.2**	**0.8**
Hay	4.9	3.5	2.1	1.6	1.1	0.4
Permanent Pasture	**2.9**	**2.1**	**1.3**	**0.9**	**0.7**	**0.2**
Slope: >9% to 15% average slope						
Continuous Soybeans						
- fall plow	**99.1**	**71.5**	**42.9**	**31.7**	**22.5**	**8.2**
- no-till	**52.2**	**37.7**	**22.6**	**16.7**	**11.8**	**4.3**
Continuous Corn						
- fall plow	72.0	52.0	31.2	23.0	16.3	5.9
- spring plow	66.6	48.1	28.9	21.3	15.1	5.5
- fall chisel	54.0	39.0	23.4	17.3	12.3	4.5
- no-till	18.0	13.0	7.8	5.8	4.1	1.5
Rotational Corn (corn-soybeans-small grains) – conventional till	**59.4**	**42.9**	**25.7**	**19.0**	**13.5**	**4.9**
Rotational Corn (corn-soybeans-small grains) – no till	16.2	11.6	7.1	5.1	3.7	1.3
Tobacco	**63.0**	**45.5**	**27.3**	**20.1**	**14.3**	**–**
Seasonal Horticultural Crops	81.0	58.5	35.1	25.9	18.4	6.7
Orchard	**18.0**	**13.0**	**7.8**	**5.8**	**4.1**	**1.5**
Hay	9.0	6.5	3.9	2.9	2.0	0.7
Permanent Pasture	**5.4**	**3.9**	**2.3**	**1.7**	**1.2**	**0.4**

Note 1: Examples are for up and down farming. If cross slope farming is used, reduce the values by 25%
Note 2: If in Waterloo, Perth, Essex, Southern Kent and Middle Wellington counties, increase the values by 33%

Table 4.32-I. Determination of Expected Average Annual Soil Loss

Factors Affecting Soil Loss	Expected Soil Loss (tons/ac/yr)					
Slope and Crop	Very Fine Sand, Loamy Very Fine Sand	Very Fine Sandy Loam, Silt Loam, Loam	Silty Clay Loam, Fine Sandy Loam, Clay Loam, Loamy Fine Sand, Sandy Clay Loam	Fine Sand, Sandy Loam, Silty Clay	Loamy Sand, Sand, Clay	Heavy Clay
Slope: 0% to 2% average slope						
Continuous Soybeans						
- fall plow	3.5	2.5	1.5	1.1	0.8	0.3
- no-till	1.8	1.3	0.8	0.6	0.4	0.2
Continuous Corn						
- fall plow	2.5	1.8	1.1	0.8	0.6	0.2
- spring plow	2.4	1.7	1.0	0.8	0.5	0.2
- fall chisel	1.9	1.4	0.8	0.6	0.4	0.2
- no-till	0.6	0.5	0.3	0.2	0.1	0.1
Rotational Corn (corn-soybeans-small grains) – conventional till	2.1	1.5	0.9	0.7	0.5	0.2
Rotational Corn (corn-soybeans-small grains) – no-till	0.6	0.4	0.3	0.2	0.1	0.0
Tobacco	2.2	1.6	1.0	0.7	0.5	--
Seasonal Horticultural Crops	2.9	2.1	1.2	0.9	0.6	0.2
Orchard	0.6	0.5	0.3	0.2	0.1	0.1
Hay	0.3	0.2	0.1	0.1	0.1	0.0
Permanent Pasture	0.2	0.1	0.1	0.1	0.0	0.0
Slope: >2% to 5% average slope						
Continuous Soybeans						
- fall plow	9.5	6.9	4.1	3.0	2.2	0.8
- no-till	5.0	3.6	2.2	1.6	1.1	0.4
Continuous Corn						
- fall plow	6.9	5.0	3.0	2.2	1.6	0.6
- spring plow	6.4	4.6	2.8	2.0	1.5	0.5
- fall chisel	5.2	3.7	2.2	1.7	1.2	0.4
- no-till	1.7	1.2	0.7	0.6	0.4	0.1
Rotational Corn (corn-soybeans-small grains) – conventional till	5.7	4.1	2.5	1.8	1.3	0.5
Rotational Corn (corn-soybeans-small grains) – no-till	1.6	1.1	0.7	0.5	0.4	0.1
Tobacco	6.1	4.4	2.6	1.9	1.4	--
Seasonal Horticultural Crops	7.8	5.6	3.4	2.5	1.8	0.6
Orchard	1.7	1.2	0.7	0.6	0.4	0.1
Hay	0.9	0.6	0.4	0.3	0.2	0.1
Permanent Pasture	0.5	0.4	0.2	0.2	0.1	0.0

Table 4.32-I. Determination of Expected Average Annual Soil Loss

Factors Affecting Soil Loss	Expected Soil Loss (tons/ac/yr)					
Slope and Crop	Very Fine Sand, Loamy Very Fine Sand	Very Fine Sandy Loam, Silt Loam, Loam	Silty Clay Loam, Fine Sandy Loam, Clay Loam, Loamy Fine Sand, Sandy Clay Loam	Fine Sand, Sandy Loam, Silty Clay	Loamy Sand, Sand, Clay	Heavy Clay
Slope: >5% to 9% average slope						
Continuous Soybeans						
- fall plow	24.0	17.3	10.4	7.7	5.4	2.0
- no-till	12.7	9.1	5.5	4.0	2.9	1.0
Continuous Corn						
- fall plow	17.5	12.6	7.6	5.6	4.0	1.4
- spring plow	16.2	11.7	7.0	5.2	3.7	1.3
- fall chisel	13.1	9.5	5.7	4.2	3.0	1.1
- no-till	4.4	3.2	1.9	1.4	1.0	0.4
Rotational Corn (corn-soybeans-small grains) – conventional till	14.4	10.4	6.2	4.6	3.3	1.2
Rotational Corn (corn-soybeans-small grains) – no-till	3.9	2.8	1.7	1.2	0.9	0.3
Tobacco	15.3	11.0	6.6	4.9	3.5	--
Seasonal Horticultural Crops	19.6	14.2	8.5	6.3	4.5	1.6
Orchard	4.4	3.2	1.9	1.4	1.0	0.4
Hay	2.2	1.6	0.9	0.7	0.5	0.2
Permanent Pasture	1.3	0.9	0.6	0.4	0.3	0.1
Slope: >9% to 15% average slope						
Continuous Soybeans						
- fall plow	44.2	31.9	19.1	14.1	10.0	3.6
- no-till	23.3	16.8	10.1	7.5	5.3	1.9
Continuous Corn						
- fall plow	32.2	23.2	13.9	10.3	7.3	2.7
- spring plow	29.7	21.5	12.9	9.5	6.7	2.5
- fall chisel	24.1	17.4	10.4	7.7	5.5	2.0
- no-till	8.0	5.8	3.5	2.6	1.8	0.7
Rotational Corn (corn-soybeans-small grains) – conventional till	26.5	19.1	11.5	8.5	6.0	2.2
Rotational Corn (corn-soybeans-small grains) – no-till	7.2	5.2	3.2	2.3	1.6	0.6
Tobacco	28.1	20.3	12.2	9.0	6.4	--
Seasonal Horticultural Crops	36.2	26.1	15.7	11.6	8.2	3.0
Orchard	8.0	5.8	3.5	2.6	1.8	0.7
Hay	4.0	2.9	1.7	1.3	0.9	0.3
Permanent Pasture	2.4	1.7	1.0	0.8	0.5	0.2

Note 1: Examples are for up and down farming. If cross slope farming is used, reduce the values by 25%

Note 2: If in Waterloo, Perth, Essex, Southern Kent and Middle Wellington counties, increase the values by 33%

Table 4.33-M. Determination of Pond Depth (Design Berm Height)

Volume Factor (m^3)	Pond Depth (design berm height in m)
390	0.50
900	0.60
1,770	0.75
3,060	0.90
4,860	1.05
7,250	1.20
10,320	1.35
14,160	1.50
18,850	1.65
24,470	1.80
31,100	2.00
38,850	2.15

Note: On heights over 2.15 m, use other design methods or reduce the ponding watershed.
To be conservative, always choose the next highest volume factor value.

Table 4.33-I. Determination of Pond Depth (Design Berm Height)

Volume Factor (ft^3)	Pond Depth (design berm height in ft)
13,500	1.5
32,000	2.0
62,500	2.5
108,000	3.0
171,500	3.5
256,000	4.0
364,500	4.5
500,000	5.0
665,500	5.5
864,000	6.0
1,098,500	6.5
1,372,000	7.0

Note: On heights over 7 ft, use other design methods or reduce the ponding watershed.
To be conservative, always choose the next highest volume factor value.

Table 4.34. Determination of Flooding Time

Type of Crop	Maximum Flooding Time
Bushland and lower value field crops (corn, soybeans, hay, small grains)	24 hours
Higher value crops (most horticulture crops)	12 hours

Notes:

- At no time should the flooding time exceed 24 hours
- The landowner must realize that flooding is an expected part of the design and must be allowed. If the landowner is unwilling to accept the flooding, consider another erosion control solution.
- Subsurface drainage within the ponding area must be designed so excess water is removed rapidly from the root zone as specified in OMAFRA Publication 29, *Drainage Guide for Ontario*

Table 4.35-M. Approximate Discharge Capacity of Rectangular Notches in Small Dams (m^3/s)

Depth of Notch D (m)	Spillway Notch Width L – metres required for the discharges indicated											
	0.6	1.2	1.8	2.4	3.3	3.7	4.3	4.9	5.5	6.1	6.7	7.3
0.15	0.065	0.13	0.19	0.26	0.32	0.39	0.45	0.51	0.58	0.64	0.71	0.77
0.30	0.18	0.36	0.54	0.72	0.91	1.09	1.27	1.45	1.63	1.81	1.99	2.17
0.45	0.33	0.67	1.00	1.33	1.67	2.00	2.33	2.66	3.00	3.33	3.66	4.00
0.60	0.51	1.03	1.54	2.05	2.56	3.08	3.59	3.25	4.61	5.13	5.64	6.15
0.75	0.72	1.43	2.14	2.87	3.58	4.30	5.01	5.73	6.45	7.16	7.88	8.60
1.00	0.94	1.88	2.83	3.77	4.71	5.65	6.59	7.53	8.48	9.42	10.36	11.30

Table 4.35-I. Approximate Discharge Capacity of Rectangular Notches in Small Dams (ft^3/s)

Depth of Notch D (ft)	Spillway Notch Width L – feet required for the discharges indicated											
	2	4	6	8	10	12	14	16	18	20	22	24
0.5	2.3	4.5	6.8	9.1	11.3	13.6	15.8	18.1	20.4	22.6	24.9	27.2
1.0	6.4	12.8	19.2	25.6	32.0	38.4	44.8	51.2	57.6	64.0	70.4	76.8
1.5	11.8	23.5	35.2	47.0	58.8	70.5	82.3	94.1	105.8	117.6	129.3	141.1
2.0	18.1	36.2	54.3	72.4	90.5	108.6	126.7	114.8	162.9	181.0	199.1	217.2
2.5	25.3	50.6	75.9	101.2	126.5	151.8	177.1	202.4	227.7	253.0	278.3	303.6
3.0	33.3	66.5	99.8	133.0	166.3	199.5	232.8	266.0	299.3	332.5	365.8	399.1

Table 4.36-M. Approximate Earth Volumes (m^3) for Various Berm Dimensions, Side Slope 2:1

Max. Depth (m)	Length of Berm (m)																	
	20	25	30	35	45	50	55	60	70	75	80	85	90	100	105	110	115	120
0.3	5	6	8	9	11	12	14	15	17	18	20	21	23	25	26	28	29	31
0.5	8	10	13	15	18	21	23	25	28	31	33	36	38	41	44	46	48	51
0.6	12	15	19	23	27	31	34	37	41	45	49	53	57	60	64	68	62	76
0.8	15	21	26	31	37	41	47	52	57	62	67	73	78	83	88	93	99	104
0.9	21	28	34	41	47	54	61	68	75	82	89	95	102	109	115	122	129	136
1.1	26	34	43	51	60	69	77	86	95	103	112	120	129	138	146	154	163	172
1.2	31	42	53	64	74	85	95	106	116	127	138	148	158	169	180	190	201	212
1.4	38	51	64	77	90	102	115	128	140	153	166	178	191	204	216	229	242	255
1.5	45	60	76	91	106	121	136	151	166	181	196	212	226	242	257	272	287	302
1.7	53	70	88	106	124	141	159	177	194	212	229	247	265	282	300	318	336	353
1.8	61	88	102	122	143	163	183	204	224	245	365	285	306	326	346	337	388	408
2.0	70	93	116	140	163	187	210	233	256	280	303	326	349	373	396	420	443	466
2.1	80	106	132	158	185	212	238	265	291	317	343	370	397	423	450	476	502	528

Note: assumed top width is 1.2 m in all calculations

Table 4.36-I. Approximate Earth Volumes (yd^3) for Various Berm Dimensions, Side Slope 2:1

Max. Depth (ft)	Length of Berm (ft)																	
	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
1.0	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1.5	10	13	17	20	23	27	30	33	37	40	43	47	50	53	57	60	63	67
2.0	15	20	25	30	35	40	44	49	54	59	64	69	74	79	84	89	94	99
2.5	20	27	34	41	48	54	61	68	75	81	88	95	102	109	115	122	129	136
3.0	27	36	44	53	62	71	80	89	98	107	116	124	133	142	151	160	169	178
3.5	34	45	56	67	79	90	101	112	124	135	146	157	169	180	191	202	213	225
4.0	41	55	69	83	97	111	124	138	152	166	180	194	207	221	235	249	263	277
4.5	50	67	83	100	117	133	150	167	183	200	217	233	250	267	283	300	317	333
5.0	59	79	99	119	138	158	178	198	217	237	257	277	296	316	336	356	375	395
5.5	69	92	115	139	162	185	208	231	254	277	300	323	346	369	392	416	439	462
6.0	80	107	133	160	187	213	240	267	293	320	347	373	400	427	453	480	507	533
6.5	91	122	152	183	213	244	274	305	335	366	396	427	457	488	518	549	579	610
7.0	104	138	173	207	242	277	311	346	380	415	449	484	519	553	588	622	657	691

Note: assumed top width is 4 ft in all calculations

Table 4.37-M. Approximate Earth Volumes (m^3) for Various Berm Dimensions, Side Slope 3:1

Max. Depth (m)	Length of Berm (m)																	
	20	25	30	35	45	50	55	60	70	75	80	85	90	100	105	110	115	120
0.3	5	7	8	10	12	14	15	17	18	21	22	24	25	28	29	31	32	34
0.5	9	12	15	18	21	24	27	30	33	36	39	41	44	47	50	54	57	60
0.6	14	18	23	28	31	36	41	45	50	54	59	63	68	73	77	82	86	91
0.8	19	25	32	38	44	51	57	63	70	76	83	89	96	102	109	115	121	128
0.9	25	34	43	51	60	68	76	85	93	102	110	119	128	136	145	153	161	170
1.1	33	44	54	66	76	87	98	109	120	131	141	153	164	174	185	196	207	218
1.2	41	54	68	82	95	109	122	136	150	163	177	190	204	218	231	245	258	272
1.4	50	67	83	99	116	132	149	166	182	199	216	232	249	265	281	298	315	331
1.5	60	80	99	119	138	158	178	198	218	238	258	278	297	317	337	357	377	397
1.7	70	93	117	140	164	187	210	234	257	281	304	327	350	373	397	421	444	467
1.8	82	109	136	163	190	217	245	272	299	326	353	381	408	435	462	489	517	544
2.0	94	125	157	188	219	250	281	313	344	375	407	438	469	501	532	563	595	626
2.1	107	143	170	214	250	285	321	357	392	428	464	499	535	571	606	642	678	713

Note: assumed top width is 1.2 m in all calculations

Table 4.37-I. Approximate Earth Volumes (yd^3) for Various Berm Dimensions, Side Slope 3:1

Max. Depth (ft)	Length of Berm (ft)																	
	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
1.0	7	9	11	13	16	18	20	22	24	27	29	31	33	36	38	40	42	44
1.5	12	16	19	23	27	31	35	39	43	47	51	54	58	62	66	70	74	78
2.0	18	24	30	36	41	47	53	59	65	71	77	83	89	95	101	107	113	119
2.5	25	33	42	50	58	67	75	83	92	100	108	117	125	133	142	150	158	167
3.0	33	44	56	67	78	89	100	111	122	133	144	156	167	178	189	200	211	222
3.5	43	57	71	86	100	114	128	143	157	171	185	200	214	228	242	257	271	285
4.0	53	71	89	107	124	142	160	178	196	213	231	249	267	284	302	320	338	356
4.5	65	87	108	130	152	173	195	217	238	260	282	303	325	347	368	390	412	433
5.0	78	104	130	156	181	207	233	259	285	311	337	363	389	415	441	467	493	519
5.5	92	122	153	183	214	244	275	306	336	367	397	428	458	489	519	550	581	611
6.0	107	142	178	213	249	284	320	356	391	427	462	498	533	569	604	640	676	711
6.5	123	164	205	246	286	327	368	409	450	491	532	573	614	655	696	737	778	819
7.0	140	187	233	280	327	373	420	467	513	560	607	653	700	747	793	840	887	933

Note: assumed top width is 4 ft in all calculations

Table 4.38-M. Approximate Earth Volumes (m^3) for Various Berm Dimensions, Side Slope 8:1

Max. Depth (m)	Length of Berm (m)																	
	20	25	30	35	45	50	55	60	70	75	80	85	90	100	105	110	115	120
0.3	8	11	13	16	18	21	24	27	29	31	34	37	40	42	45	47	50	53
0.5	15	21	25	31	36	41	46	51	56	61	67	71	76	82	86	92	97	102
0.6	25	33	41	50	58	67	75	83	92	99	108	116	125	133	141	150	158	166
0.8	37	49	61	73	86	98	110	122	135	148	160	172	184	196	209	221	233	245
0.9	51	68	85	102	119	136	153	170	187	204	221	238	255	272	289	306	323	339
1.1	67	90	112	135	157	180	202	225	247	270	292	314	337	359	382	404	427	450
1.2	86	116	144	172	201	229	258	287	316	344	373	401	430	459	488	517	545	574
1.4	107	143	178	214	250	285	321	357	392	428	464	499	535	571	606	642	678	713
1.5	130	174	217	261	304	347	391	434	478	521	564	608	651	695	738	781	825	869
1.7	156	208	260	311	363	415	467	519	571	623	675	727	779	830	882	934	986	1,038
1.8	183	245	306	367	428	489	550	611	673	734	795	856	917	979	1,040	1,101	1,162	1,223
2.0	213	284	356	427	498	570	641	712	783	854	925	996	1,067	1,138	1,210	1,281	1,353	1,424
2.1	245	328	410	492	573	655	737	820	901	983	1,065	1,147	1,229	1,311	1,393	1,475	1,557	1,638

Note: assumed top width is 1.2 m in all calculations

Table 4.38-I. Approximate Earth Volumes (yd^3) for Various Berm Dimensions, Side Slope 8:1

Max. Depth (ft)	Length of Berm (ft)																	
	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
1.0	10	14	17	21	24	28	31	35	38	41	45	48	52	55	59	62	66	69
1.5	20	27	33	40	47	53	60	67	73	80	87	93	100	107	113	120	127	133
2.0	33	43	54	65	76	87	98	109	120	130	141	152	163	174	185	196	206	217
2.5	48	64	80	96	112	128	144	160	177	193	209	225	241	257	273	289	305	321
3.0	67	89	111	133	156	178	200	222	244	267	289	311	333	356	378	400	422	444
3.5	88	118	147	176	206	235	264	294	323	353	382	411	441	470	500	529	558	588
4.0	113	150	188	225	263	300	338	375	413	450	488	525	563	600	638	676	713	751
4.5	140	187	233	280	327	373	420	467	513	560	607	653	700	747	793	840	887	933
5.0	170	227	284	341	398	454	511	568	625	681	738	795	852	909	965	1,022	1,079	1,136
5.5	204	272	340	407	475	543	611	679	747	815	883	951	1,019	1,086	1,154	1,222	1,290	1,358
6.0	240	320	400	480	560	640	720	800	880	960	1,040	1,120	1,200	1,280	1,360	1,440	1,520	1,600
6.5	279	372	465	559	652	745	838	931	1,024	1,117	1,210	1,303	1,396	1,489	1,582	1,676	1,769	1,862
7.0	321	429	536	643	750	857	964	1,072	1,179	1,286	1,393	1,500	1,607	1,715	1,822	1,929	2,036	2,143

Note: assumed top width is 4 ft in all calculations

Water and Sediment Control Basin (WASCoB) Single WASCoB System – Example Problem #1

Runoff from a 4 ha (10 ac) watershed is causing erosion concerns. The land typically follows a corn-bean-wheat (straight row crop) rotation, (poor hydrologic condition). The watershed is comprised of Harriston silt loam soils (Hydrologic Soil Group B). The slope of the watershed is 1%. Design a water and sediment control basin (WASCoB) for this site.

A summary of the needed design input follows:

- watershed area above the floodwater storage = 4 ha (10 ac)
- watershed slope = 1%
- runoff curve number = 81 (use 80), based on a hydrologic soil group of B, straight row crops and a poor hydrologic condition
- slope upstream from storage = 2%
- average side slopes at point of proposed berm construction = 4%
- outlet pipe has a slope = 0.5%
- a single WASCoB is proposed, therefore use Water and Sediment Control Basin (WASCoB) Design Information Sheet (Single WASCoB System) to assist with design calculations

Water and Sediment Control Basin (WASCoB) Design Information Sheet (Single WASCoB System) – Example Problem #1

Note: Use this Design Information Sheet if only **one** WASCoB is to be constructed and drained through a single subsurface tile outlet.

WASCoB Identification #1

1.	Watershed area	4 ha	10 ac
2.	Watershed slope		1%
3.	Runoff curve number from Tables 2.2 – 2.4		80
4.	Peak flow from watershed for 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	0.111 m^3/s	3.92 ft^3/s
5.	Peak flow from watershed for 25-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	0.166 m^3/s	5.85 ft^3/s
6.	Obtain the storm duration for a10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)		1.05 hrs
7.	Obtain the storm volume expected for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	316 m^3	11,174 ft^3
8.	Determine slope of ponding area upstream from storage berm from field measurements		2%
9.	Determine slope of side of ponding area upstream from storage berm from field measurements. If side slopes are different use the average of the two slopes.		4%
10.	Determine soil loss expected above ponding area from Table 4.32-M (4.32-I)	3.4 tonnes/ha	1.5 tons/ac/yr

11. Storage required for eroded soil for 15-year life expectancy Line (10) x Line (1) x 15 = 3.4 x 4 x 15 = 204 tonnes x 0.68 m^3/tonne = <u>139</u> m^3 (1.5 x 10 x 15 = 225 tons x 21.7 ft^3/ton = <u>4,883</u> ft^3)	139 m^3	4,883 ft^3
12. Total pond storage Line (7) + Line (11) = <u>316</u> + <u>139</u> = <u>455</u> m^3 (<u>16,057</u> ft^3)	455 m^3	16,057 ft^3
13. Determine volume factor Line (12) x Line (8) x Line (9) = <u>455</u> x <u>2</u> x <u>4</u> = <u>3,640</u> m^3 (<u>128,456</u> ft^3)	3,640 m^3	128,456 ft^3
14. Obtain pond depth (design berm height) from Table 4.33-M (4.33-I)	1.05 m	3.5 ft
15. Determine pond length $\frac{\text{Line (14)}}{\text{Line (8)}} \times 100 = \frac{1.05}{4} \times 100$ = <u>52.5</u> m (<u>175</u> ft)	52.5 m	175 ft
16. Determine maximum pond width $\frac{\text{Line (14)}}{\text{Line (9)}} \times 200 = \frac{1.05}{4} \times 200$ = <u>52.5</u> m (<u>175</u> ft) If pond side slopes vary by more than 50%, the calculated pond width will be different than the actual field pond width. For accuracy, separate the sides and calculate individually.	52.5 m	175 ft
17. Obtain maximum flooding time from Table 4.34		24 hrs
18. Determine outlet capacity $\frac{\text{Line (7)}}{\text{Line (17)} - \text{Line (6)}} \times 0.000277 = \frac{316}{24 - 1.05} \times 0.000277$ = <u>0.0038</u> m^3/s (<u>0.135</u> ft^3/s)	0.0038 m^3/s	0.135 ft^3/s
19. Determine the riser pipe and horizontal pipe sizes. Complete the following:		
– horizontal pipe slope		0.5 %
– horizontal pipe diameter (Figure 4.31)	150 mm	6 in
– riser pipe diameter (Table 4.19-M (4.19-I))	150 mm	6 in
– orifice diameter (if required)	N/A	N/A
20. Check emergency overflow spillway type to be used	☑ Grass lined	☐ Rock lined
21. Determine emergency overflow spillway capacity from Line (5)	0.166 m^3/s	5.85 ft^3/s
22. Determine emergency overflow spillway notch dimensions from Table 4.35-M (4.35-I) to meet capacity requirements from Line (21)		
– notch width (L)	1.8 m	6 ft
– notch depth (D)	0.15 m	0.5 ft
23. Actual berm height (Note: Freeboard is 10% of Line (14) to maximum of 0.15 m (6 in.)) Line (14) + freeboard + notch depth (D) (Line (22)) = <u>1.05</u> + <u>0.15</u> + <u>0.15</u> = <u>1.35</u> m (<u>4.5</u> ft)	1.35 m	4.5 ft

24. Actual berm length $\frac{\text{Line (23)}}{\text{Line (9)}} \times 200 = \frac{1.35}{4} \times 200 = \underline{67.5}$ m ($\underline{225}$ ft)	67.5 m	225 ft
25. Berm side slope (minimum 2:1, maximum 8:1)		3:1
26. Top width of berm default width of 1.2 m (4 ft) (Note: Default width of 1.2 m (4 ft))	1.2 m	4 ft
27. Bottom width of berm Line (26) + 2 x Line (23) x Line (25)) = $\underline{1.2}$ + (2 x $\underline{1.35}$ x $\underline{3}$) = $\underline{9.3}$ m ($\underline{31}$ ft)	9.3 m	31 ft
28. Earth volume for berm from Table 4.36-M to 4.38-M (4.36-I to 4.38-I)	178 m^3	244 yd^3

Summary of WASCoB (Example Problem #1) Design Results

- A storage pond 52.5 m (175 ft) long, 52.5 m (175 ft) wide and 1.05 m (3.5 ft) deep is required.
- Outlet capacity of 0.0038 m^3/s (0.135 ft^3/s) is required.
- A small capacity riser pipe system is used.
- A 150 mm (6 in.) horizontal pipe with a 150 mm (6 in.) vertical riser pipe is adequate.
- A grassed lined emergency overflow spillway with a notch width (L) of 1.8 m (6 ft) and a notch depth (D) of 0.15 m (0.5 ft) is proposed.
- The final berm dimensions are 67.5 m (225 ft) in length, 1.2 m (4 ft) top width, 3:1 side slopes and having an earth volume of 178 m^3 (244 yd^3).

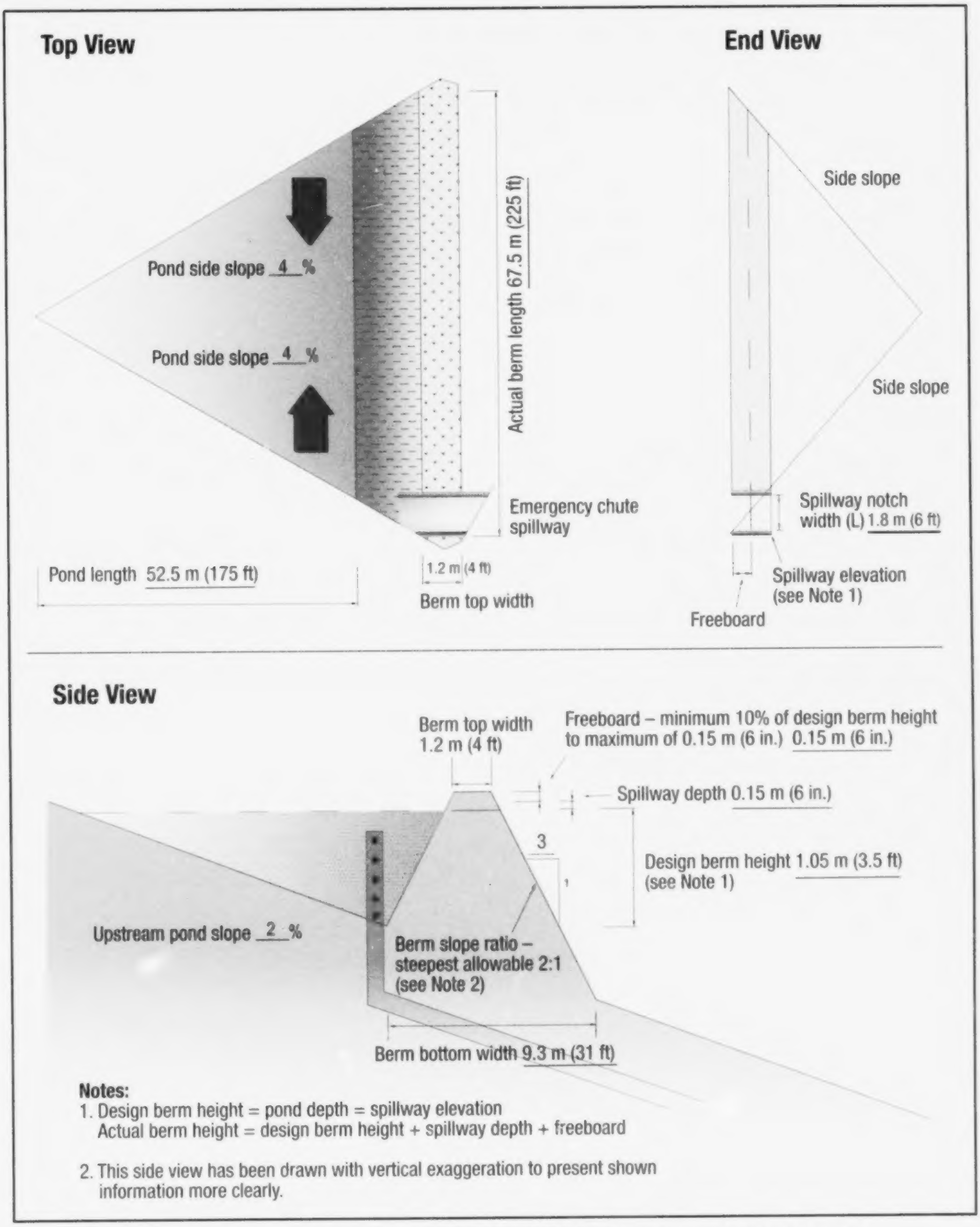


Figure 4.36. Water and Sediment Control Basin (WASCoB) – Example Problem #1

Water and Sediment Control Basin (WASCoB) Multiple WASCoB System – Example Problem #2

Runoff from a 14 ha (35 ac) watershed is causing erosion along a single 450 m (1,500 ft) drainageway on a dairy farm. Cropping consists of rotational corn (row crop) grown on the contour. Soils are Camilla fine sandy loam and there is no tile drainage on the farm. The hydrologic soil group is B and the hydrologic condition is good.

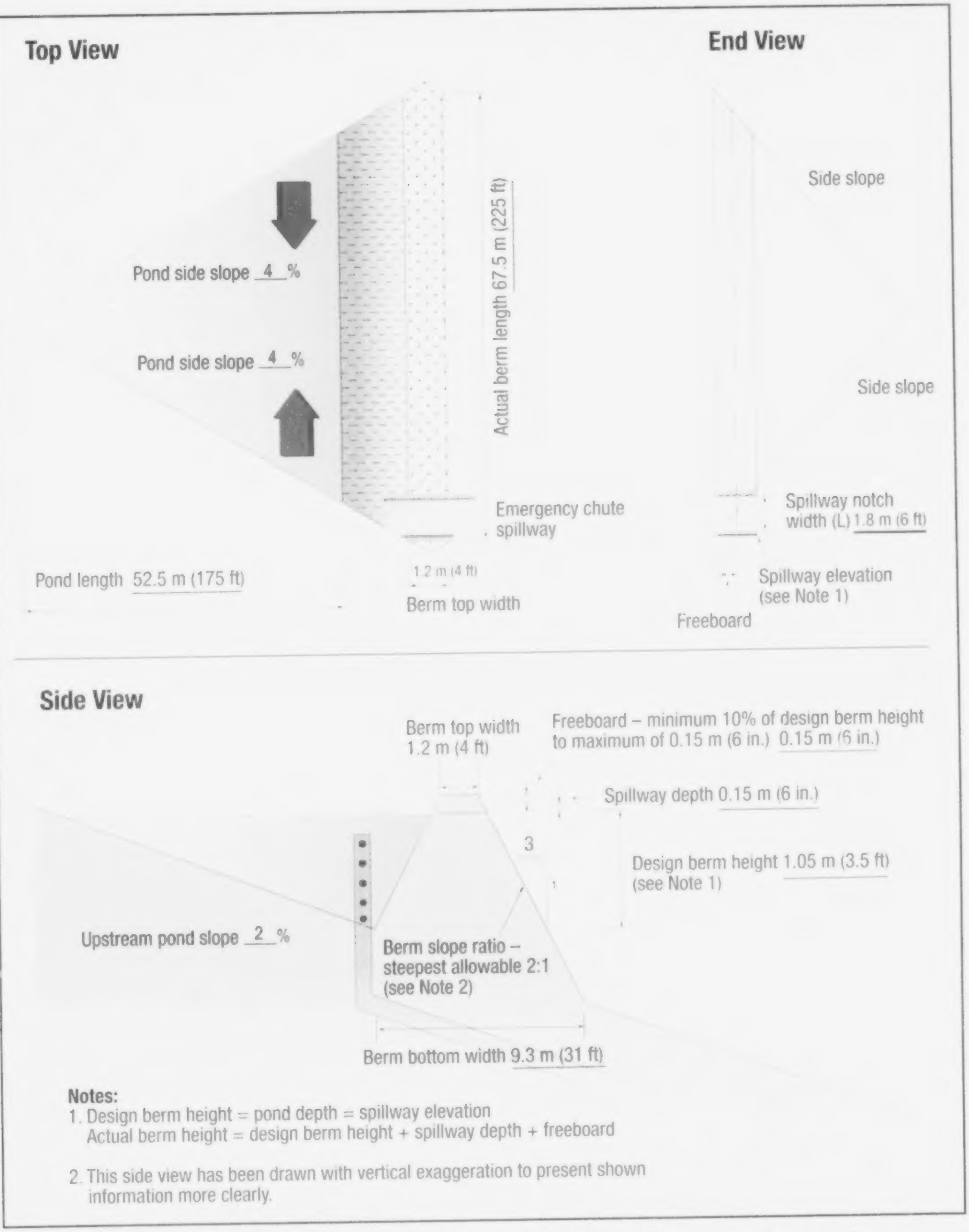


Figure 4.36. Water and Sediment Control Basin (WASCoB) – Example Problem #1

Water and Sediment Control Basin (WASCoB) Multiple WASCoB System – Example Problem #2

Runoff from a 14 ha (35 ac) watershed is causing erosion along a single 450 m (1,500 ft) drainageway on a dairy farm. Cropping consists of rotational corn (row crop) grown on the contour. Soils are Camilla fine sandy loam and there is no tile drainage on the farm. The hydrologic soil group is B and the hydrologic condition is good.

The preferred option for controlling the erosion is the construction of water and sediment control basins. In looking at the landscape along the drainageway, there's an existing crop boundary that could make a good location for a WASCoB, and also a location where the drainageway narrows that would make another suitable WASCoB location. Two WASCoBs are proposed, breaking the watershed up into the following:

WASCoB 1

- area of watershed above proposed WASCoB 1 = 10 ha (25 ac)
- watershed slope = 2%
- runoff curve number = 75
- slope upstream from storage = 1.5%
- average side slopes = 2.5%
- outlet pipe will have a slope = 1.5%

WASCoB 2

- area of watershed above proposed WASCoB 2 = 4 ha (10 ac)
- watershed slope = 2%
- runoff curve number = 75
- slope upstream from storage = 2%
- average side slopes = 3%
- outlet pipe will have a slope = 2%

Water and Sediment Control Basin (WASCoB) Design Information Sheet (Multiple WASCoB System) – Example Problem #2

Note: Use this Design Information Sheet if **more than one** WASCoB is to be constructed and drained through a single subsurface tile outlet.

WASCoB Number 1 of 2

1. Watershed area	10 ha	25 ac
2. Watershed slope		2%
3. Runoff curve number from Tables 2.2 – 2.4		75
4. Peak flow from watershed for 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	0.175 m^3/s	6.19 ft^3/s
5. Peak flow from watershed for 25-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	0.274 m^3/s	9.67 ft^3/s
6. Obtain the storm duration for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)		2.0 hrs
7. Obtain the storm volume expected for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	904 m^3	31,913 ft^3
8. Determine slope of ponding area upstream from storage berm from field measurements		1.5%
9. Determine slope of side of ponding area upstream from storage berm from field measurements. If side slopes are different use the average of the two slopes.		2.5%
10. Determine soil loss expected above ponding area from Table 4.32-M (4.32-I)	1.5 tonnes/ha/yr	0.7 tons/ac/yr

11. Storage required for eroded soil for 15-year life expectancy Line (10) x Line (1) x 15 = 1.5 x 10 x 15 = 225 tonnes x 0.68 m^3/tonne = 153 m^3 (0.7 x 25 x 15 = 263 tons x 21.7 ft^3/ton = 5,707 ft^3)	153 m^3	5,707 ft^3
12. Total pond storage Line (7) + Line (11) = 904 + 153 = 1,057 m^3 (37,620 ft^3)	1,057 m^3	37,620 ft^3
13. Determine volume factor Line (12) x Line (8) x Line (9) = 1,057 x 1.5 x 2.5 = 3,964 m^3 (141,075 ft^3)	3,964 m^3	141,075 ft^3
14. Obtain pond depth (design berm height) from Table 4.33-M (4.33-I)	1.05 m	3.5 ft
15. Determine pond length $\frac{\text{Line (14)}}{\text{Line (8)}} \times 100 = \frac{1.05}{1.5} \times 100 = \underline{70}$ m ($\underline{233}$ ft)	70 m	233 ft
16. Determine maximum pond width $\frac{\text{Line (14)}}{\text{Line (9)}} \times 200 = \frac{1.05}{2.5} \times 200 = \underline{84}$ m ($\underline{280}$ ft) If pond side slopes vary by more than 50%, the calculated pond width will be different than the actual field pond width. For accuracy, separate the sides and calculate individually.	84 m	280 ft
17. Obtain maximum flooding time from Table 4.34		24 hrs
18. Determine outlet capacity $\frac{\text{Line (7)}}{\text{Line (17)} - \text{Line (6)}} \times 0.000277 = \frac{904}{24 - 2.0} \times 0.000277$ = 0.0114 m^3/s (0.40 ft^3/s)	0.0114 m^3/s	0.40 ft^3/s
19. Horizontal pipe capacity required (this WASCoB) from Line (18)	0.0114 m^3/s	0.40 ft^3/s
20. Riser pipe diameter required (this WASCoB) from Table 4.19-M (4.19-I)	150 mm	6 in.
21. Maximum flow through riser pipe (this WASCoB) from Table 4.19-M to 4.20-M (4.19-I to 4.20-I)	0.057 m^3/s	2.0 ft^3/s
22. If applicable, orifice plate diameter used (this WASCoB) from Table 4.21-M to 4.22-M (4.21-I to 4.22-I), attempt to equal or slightly exceed Line (19) value	N/A	N/A
23. If applicable, maximum flow through riser pipe orifice plate (this WASCoB) from Table 4.21-M to 4.22-M (4.21-I to 4.22-I)	N/A	N/A
24. Horizontal pipe flow from Line (31) for upper WASCoB(s) (enter 0 if this is the upper WASCoB)	0 m^3/s	0 ft^3/s
25. Minimum horizontal pipe flow (below this WASCoB, i.e., including this WASCoB + upper WASCoB flows) Line (19) + Line (24) = 0.0114 + 0 = 0.0114 m^3/s (0.40 ft^3/s)	0.0114 m^3/s	0.40 ft^3/s
26. Minimum horizontal pipe slope (below this WASCoB)		1.5%
27. Horizontal pipe size required (below this WASCoB) using flow from Line (25), pipe slope from Line (26) and Figure 4.31	150 mm	6 in.

28. Maximum possible flow in horizontal pipe using pipe size from Line (27), pipe slope from Line (26) (below this WASCoB) and Figure 4.31	0.014 m^3/s	0.49 ft^3/s
29. Extra horizontal pipe capacity (below this WASCoB) Line (28) – Line (24) = 0.014 - 0 = 0.014 m^3/s (0.49 ft^3/s)	0.014 m^3/s	0.49 ft^3/s
30. Restricting flow (identify as the smallest value of Line (21), Line (23) (if applicable, i.e. an orifice plate is used) and Line (29)); if no orifice plate used, Line (23) = Line (21), do not insert 0 value	0.014 m^3/s	0.49 ft^3/s
31. Horizontal pipe flow transferred to lower WASCoB Line (30) + Line (24) = 0.014 + 0 = 0.014 m^3/s (0.49 ft^3/s) If the value from Line (31) is considerably less than Line (28), consider increasing water inflow, i.e. increase riser pipe size at this WASCoB location up to maximum value of Line (28).	0.014 m^3/s	0.49 f^3/s
32. Surface water transfer from Line (33) for upper WASCoB(s) Enter 0 if this is upper WASCoB	0 m^3/s	0 ft^3/s
33. Surface water transfer to lower WASCoB Line (32) + Line (5) (this WASCoB) = 0 + 0.274 = 0.274 m^3/s (9.67 ft^3/s)	0.274 m^3/s	9.67 ft^3/s
34. Check emergency overflow spillway type to be used	☑ Grass lined	☐ Rock lined
35. Determine emergency overflow spillway capacity from Line (33)	0.274 m^3/s	9.67 ft^3/s
36. Determine emergency overflow spillway notch dimensions from Table 4.35-M (4.35-I) to meet capacity requirements from Line (35)		
– notch width (L)	3.3 m	10 ft
– notch depth (D)	0.15 m	0.5 ft
37. Actual berm height (Note: Freeboard is 10% of Line (14) to maximum of 0.15 m (6 in.)) Line (14) + freeboard + notch depth = 1.05 + 0.15 + 0.15 = 1.35 m (4.5 ft)	1.35 m	4.5 ft
38. Actual berm length $\frac{\text{Line (37)}}{\text{Line (9)}} \times 200 = \frac{1.35}{2.5} \times 200$ = 108 m (360 ft)	108 m	360 ft
39. Berm side slope (minimum 2:1, maximum 8:1)		3:1
40. Top width of berm default width of 1.2 m (4 ft)	1.2 m	4 ft
41. Bottom width of berm Line (40) + (2 x Line (37) x Line (39)) = 1.2 + (2 x 1.35 x 3) = 9.3 m (31 ft)	9.3 m	31 ft
42. Earth volume for berm from Table 4.36-M to 4.38-M (4.36-I to 4.38-I)	291 m^3	390 yd^3

Proceed with the design of the next (lower) Water and Sediment Control Basin. Complete a separate Water and Sediment Control Basin (WASCoB) Design Information Sheet (Multiple WASCoB System).

WASCoB Number 2 of 2

1.	Watershed area	4 ha	10 ac
2.	Watershed slope		2%
3.	Runoff curve number from Tables 2.2 – 2.4		75
4.	Peak flow from watershed for 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	0.072 m^3/s	2.53 ft^3/s
5.	Peak flow from watershed for 25-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	0.112 m^3/s	3.97 ft^3/s
6.	Obtain the storm duration for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)		1.8 hrs
7.	Obtain the storm volume expected for a 10-year storm from Table 4.25-M to 4.31-M (4.25-I to 4.31-I)	327 m^3	11,562 ft^3
8.	Determine slope of ponding area upstream from storage berm from field measurements		2%
9.	Determine slope of side of ponding area upstream from storage berm from field measurements. If side slopes are different use the average of the two slopes.		3%
10.	Determine soil loss expected above ponding area from Table 4.32-M (4.32-I)	1.5 tonnes/ha/yr	0.7 tons/ac/yr
11.	Storage required for eroded soil for 15-year life expectancy Line (10) x Line (1) x 15 = 1.5 x 4 x 15 = 90 tonnes x 0.68 m^3/tonne = 61 m^3 (0.7 x 10 x 15 = 105 tons x 21.7 ft^3/ton = 2,279 ft^3)	61 m^3	2,279 ft^3
12.	Total pond storage Line (7) + Line (11) = 327 + 61 = 388 m^3 (13,841 ft^3)	388 m^3	13,841 ft^3
13.	Determine volume factor Line (12) x Line (8) x Line (9) = 388 x 2 x 3 = 2,328 m^3 (83,046 ft^3)	2,328 m^3	83,046 ft^3
14.	Obtain pond depth (design berm height) from Table 4.33-M (4.33-I)	0.90 m	3.0 ft
15.	Determine pond length $\frac{\text{Line (14)}}{\text{Line (8)}} \times 100 = \frac{0.90}{2} \times 100 = \underline{45}$ m ($\underline{150}$ ft)	45 m	150 ft
16.	Determine maximum pond width $\frac{\text{Line (14)}}{\text{Line (9)}} \times 200 = \frac{0.90}{3} \times 200 = \underline{60}$ m ($\underline{200}$ ft) If pond side slopes vary by more than 50%, the calculated pond width will be different than the actual field pond width. For accuracy, separate the sides and calculate individually.	60 m	200 ft
17.	Obtain maximum flooding time from Table 4.34		24 hrs
18.	Determine outlet capacity $\frac{\text{Line (7)}}{\text{Line (17)} - \text{Line (6)}} \times 0.000277 = \frac{327}{24 - 1.8} \times 0.000277$ = 0.0041 m^3/s (0.145 ft^3/s)	0.0041 m^3/s	0.145 ft^3/s
19.	Horizontal pipe capacity required (this WASCoB from Line (18))	0.0041 m^3/s	0.145 ft^3/s

20. Riser pipe diameter required (this WASCoB) from Table 4.19-M (4.19-I)	150 mm	6 in.
21. Maximum flow through riser pipe (this WASCoB) from Table 4.19-M to 4.20-M (4.19-I to 4.20-I)	0.057 m^3/s	2.0 ft^3/s
22. If applicable, orifice plate diameter used (this WASCoB) from Table 4.21-M to 4.22-M (4.21-I to 4.22-I), attempt to equal or slightly exceed Line (19) value	N/A	N/A
23. If applicable, maximum flow through riser pipe orifice plate (this WASCoB) from Table 4.21-M to 4.22-M (4.21-I to 4.22-I)	N/A	N/A
24. Horizontal pipe flow from Line (31) for upper WASCoB(s) (enter 0 if this is the upper WASCoB)	0.014 m^3/s	0.49 ft^3/s
25. Minimum horizontal pipe flow (below this WASCoB, i.e., including this WASCoB + upper WASCoB flows) Line (19) + Line (24) = <u>0.0041</u> + <u>0.014</u> = <u>0.0181</u> m^3/s (<u>0.635</u> ft^3/s)	0.0181 m^3/s	0.635 ft^3/s
26. Minimum horizontal pipe slope (below this WASCoB)		2%
27. Horizontal pipe size required (below this WASCoB) using flow from Line (25), pipe slope from Line (26) and Figure 4.31	200 mm	8 in.
28. Maximum possible flow in horizontal pipe using pipe size from Line (27), pipe slope from Line (26) (below this WASCoB) and Figure 4.31	0.033 m^3/s	1.17 ft^3/s
29. Extra horizontal pipe capacity (below this WASCoB) Line (28) – Line (24) = <u>0.033</u> - <u>0.014</u> = <u>0.019</u> m^3/s (<u>0.68</u> ft^3/s)	0.019 m^3/s	0.68 ft^3/s
30. Restricting flow (identify as the smallest value of Line (21), Line (23) (if applicable, i.e. an orifice plate is used) and Line (29)); if no orifice plate used, Line (23) = Line (21), do not insert 0 value	0.019 m^3/s	0.68 ft^3/s
31. Horizontal pipe flow transferred to lower WASCoB Line (30) + Line (24) = <u>0.019</u> + <u>0.014</u> = <u>0.033</u> m^3/s (<u>1.17</u> ft^3/s) If the value from Line (31) is considerably less than Line (28), consider increasing water inflow, i.e. increase riser pipe size at this WASCoB location up to maximum value of Line (28)	0.033 m^3/s	1.17 ft^3/s
32. Surface water transfer from Line (33) for upper WASCoB(s) Enter 0 if this is upper WASCoB	0.274 m^3/s	9.67 ft^3/s
33. Surface water transfer to lower WASCoB Line (32) + Line (5) (this WASCoB) = <u>0.274</u> + <u>0.112</u> = <u>0.386</u> m^3/s (<u>13.6</u> ft^3/s)	0.386 m^3/s	13.6 ft^3/s
34. Check emergency overflow spillway type to be used	☑ Grass lined	☐ Rock lined
35. Determine emergency overflow spillway capacity from Line (33)	0.386 m^3/s	13.6 ft^3/s
36. Determine emergency overflow spillway notch dimensions from Table 4.35-M (4.35-I) to meet capacity requirements from Line (35)		
– notch width (L)	3.7 m	12 ft
– notch depth (D)	0.15 m	0.5 ft

37. Actual berm height (Note: Freeboard is 10% of Line (14) to maximum of 0.15 m (6 in.)) Line (14) + freeboard + notch depth = 0.90 + 0.1 + 0.15 = 1.15 m (3.8 ft)	1.15 m	3.8 ft
38. Actual berm length $\frac{\text{Line (37)}}{\text{Line (9)}} \times 200 = \frac{1.15}{3} \times 200 = \underline{77}$ m ($\underline{253}$ ft)	77 m	253 ft
39. Berm side slope (minimum 2:1, maximum 8:1)		3:1
40. Top width of berm default width of 1.2 m (4 ft)	1.2 m	4 ft
41. Bottom width of berm Line (40) + (2 x Line (37) x Line (39)) = 1.2 + (2 x 1.15 x 3) = 8.1 m (27 ft)	8.1 m	27 ft
42. Earth volume for berm from Table 4.36-M to 4.38-M (4.36-I to 4.38-I)	169 m^3	225 yd^3

Design of the lower WASCoB in this two WASCoB example is now complete. For WASCoB systems with more than two WASCoBs, complete a separate Water and Sediment Control Basin (WASCoB) Design Information Sheet (Multiple WASCoB System) for each WASCoB in the multiple WASCoB system until all WASCoBs have been designed.

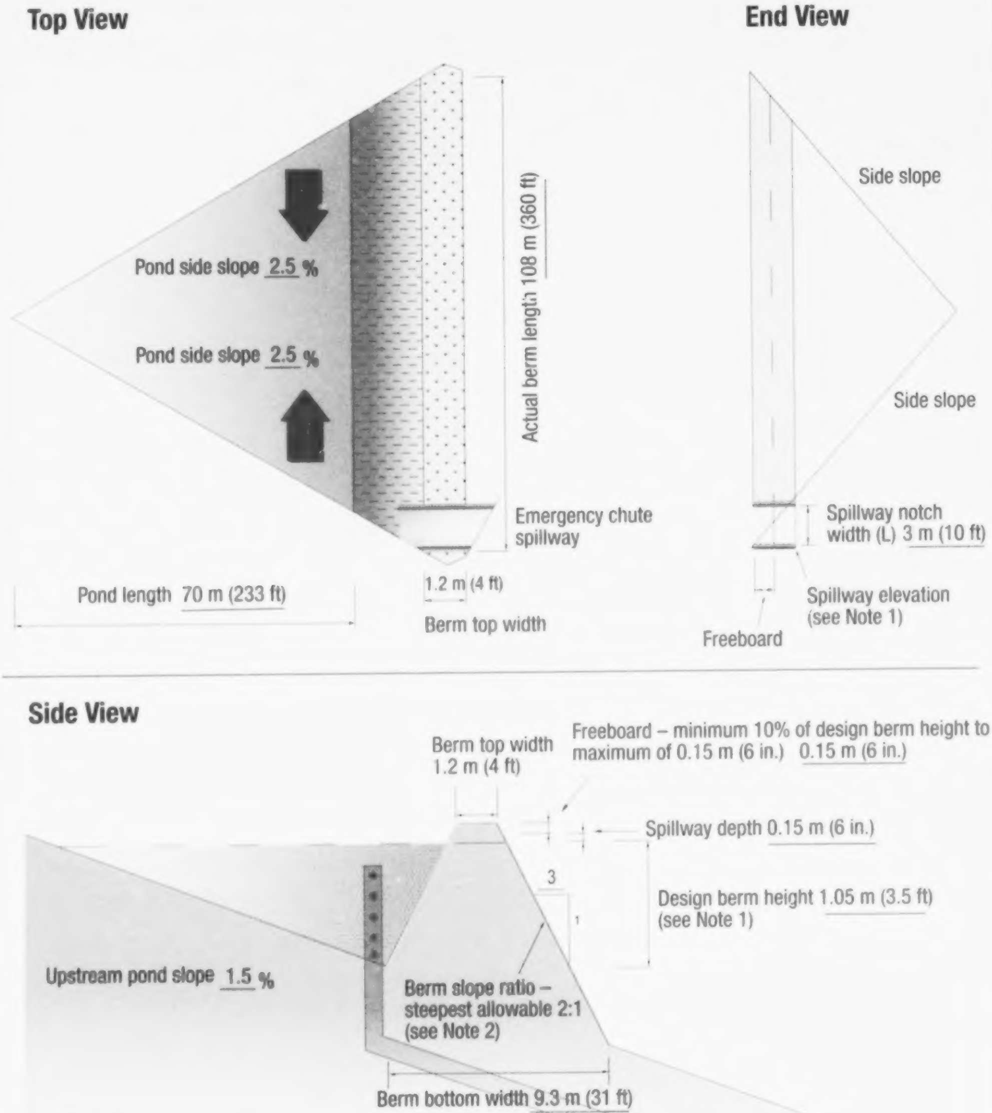
Summary of WASCoB (Example Problem #2) Design Results

Upper WASCoB (Number 1 of 2)

- A storage pond 70 m (233 ft) long, 84 m (280 ft) wide and 1.05 m (3.5 ft) deep is required.
- Outlet capacity of 0.0114 m^3/s (0.40 ft^3/s) is required.
- A small capacity riser pipe system can be used.
- A 150 mm (6 in.) horizontal pipe with 150 mm (6 in.) vertical riser pipe is adequate.
- A grass lined emergency overflow spillway with a notch width (L) of 3.3 m (10 ft) and a notch depth (D) of 0.15 m (0.5 ft) is proposed.
- The final berm dimensions are 108 m (360 ft) length, 1.2 m (4 ft) top width, 3:1 side slopes and having an earth volume of 291 m^3 (390 yd^3).

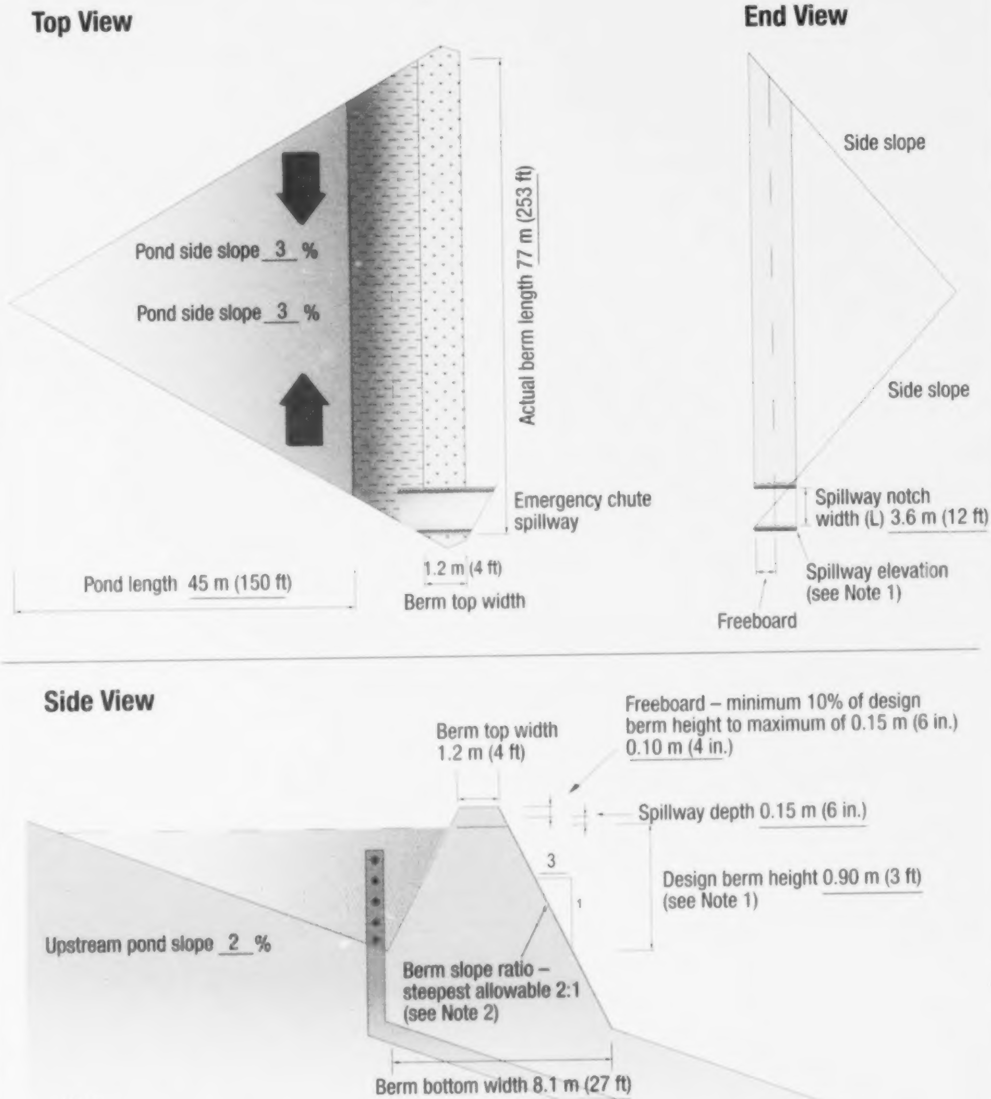
Lower WASCoB (Number 2 of 2)

- A storage pond 45 m (150 ft) long, 60 m (200 ft) wide and 0.90 m (3 ft) deep is required.
- Outlet capacity of 0.0041 m^3/s (0.145 ft^3/s) is required.
- A small capacity riser pipe system can be used.
- A 200 mm (8 in.) horizontal pipe with 150 mm (6 in.) vertical riser pipe is adequate.
- A grass lined emergency overflow spillway with a notch width (L) of 3.7 m (12 ft) and a notch depth (D) of 0.15 m (0.5 ft) is proposed.
- The final berm dimensions are 77 m (253 ft) length, 1.2 m (4 ft) top width, 3:1 side slopes and having an earth volume of 169 m^3 (225 yd^3).



Notes:
1. Design berm height = pond depth = spillway elevation
   Actual berm height = design berm height + spillway depth + freeboard
2. This side view has been drawn with vertical exaggeration to present shown information more clearly.

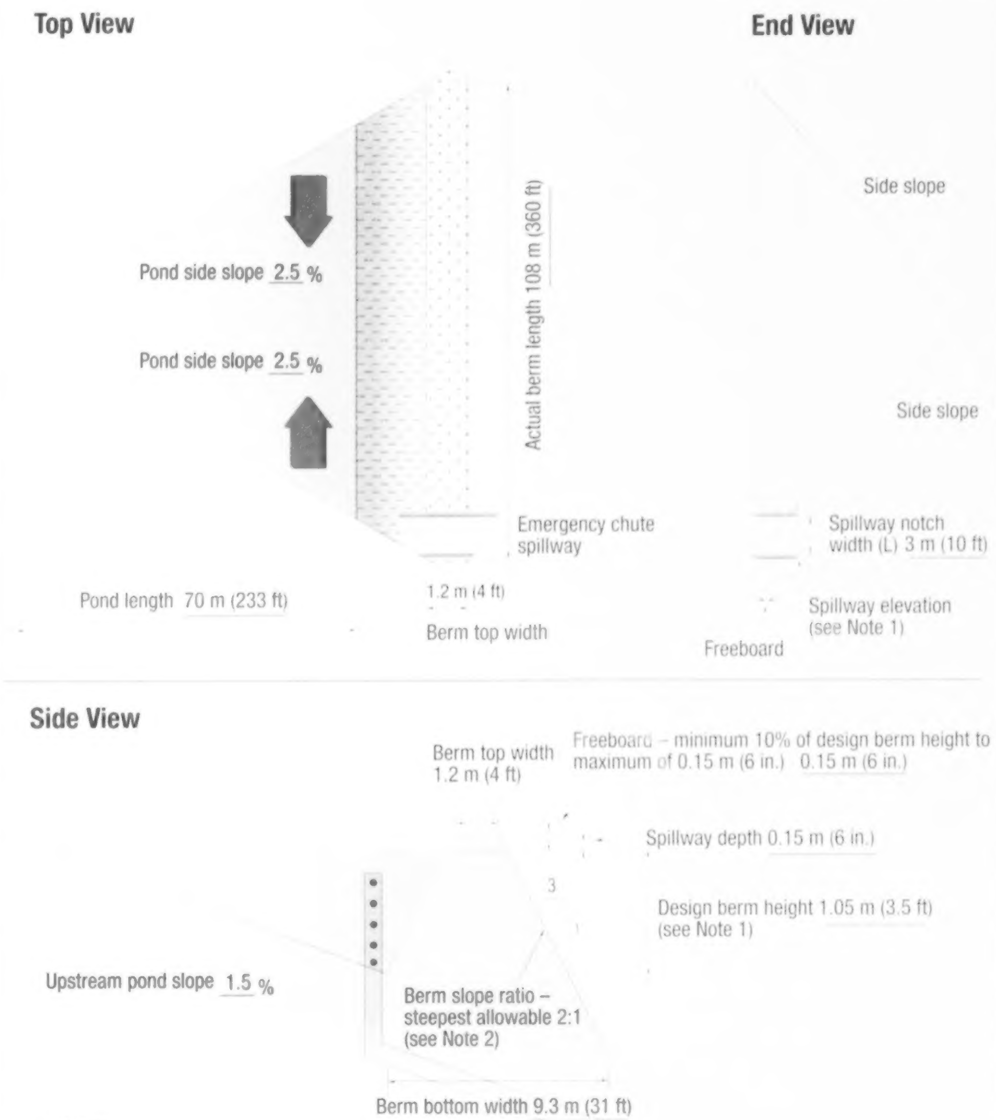
Figure 4.37. Water and Sediment Control Basin (WASCoB) – Example Problem #2, Upper WASCoB (Number 1 of 2)



Notes:

1. Design berm height = pond depth = spillway elevation
   Actual berm height = design berm height + spillway depth + freeboard
2. This side view has been drawn with vertical exaggeration to present shown information more clearly.

Figure 4.38. Water and Sediment Control Basin (WASCoB) – Example Problem #2, Lower WASCoB (Number 2 of 2)



Notes:

1. Design berm height = pond depth = spillway elevation
   Actual berm height = design berm height + spillway depth + freeboard
2. This side view has been drawn with vertical exaggeration to present shown information more clearly.

Figure 4.37. Water and Sediment Control Basin (WASCoB) – Example Problem #2, Upper WASCoB (Number 1 of 2)

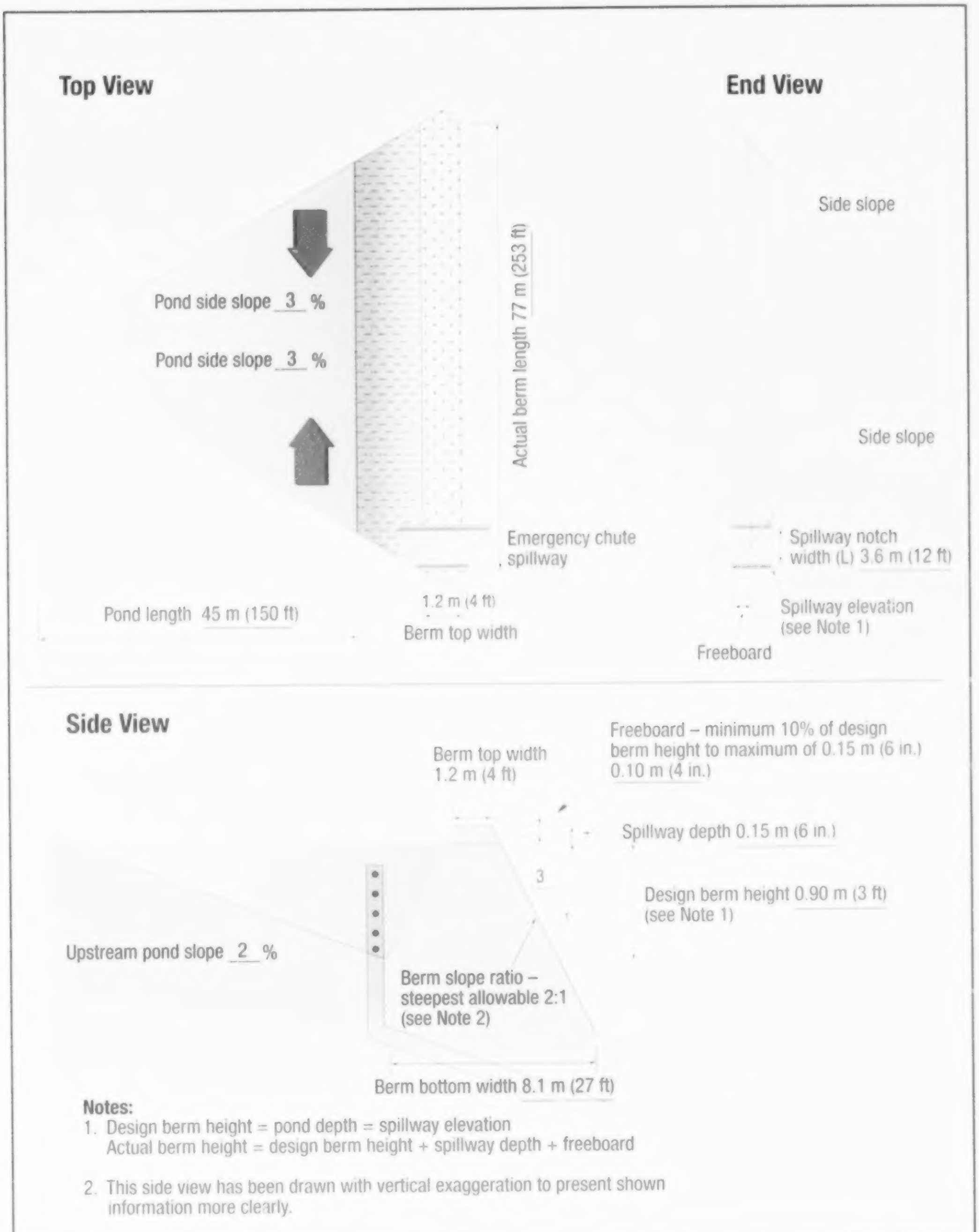


Figure 4.38. Water and Sediment Control Basin (WASCoB) – Example Problem #2, Lower WASCoB (Number 2 of 2)

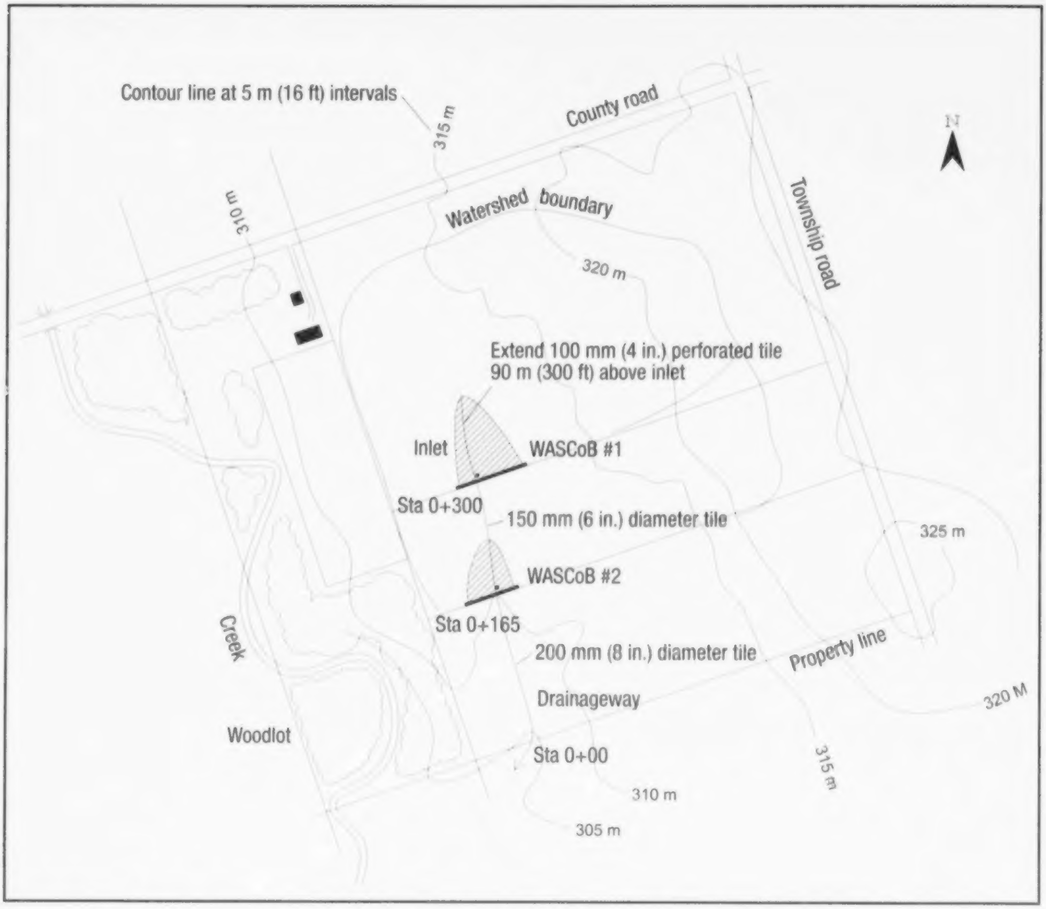


Figure 4.39. Water and Sediment Control Basin (WASCoB) – Example Problem #2, Plan View

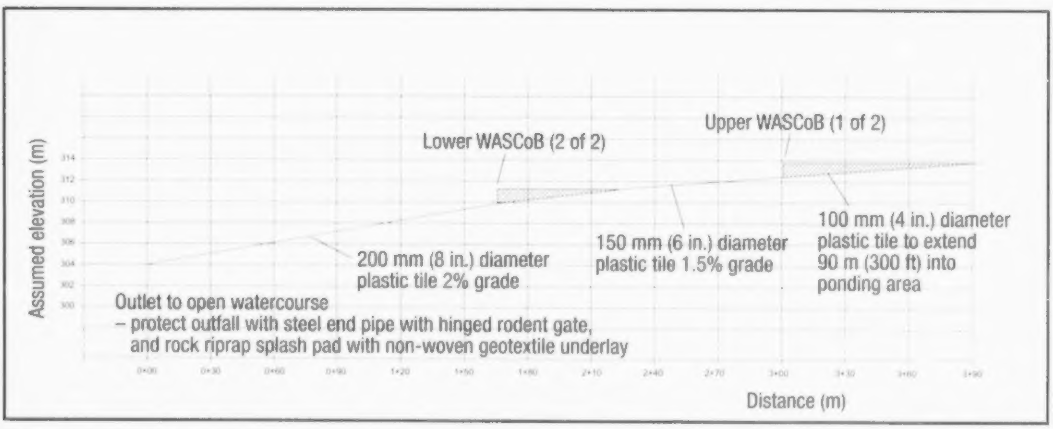


Figure 4.40. Water and Sediment Control Basin (WASCoB) –
Example Problem #2, Profile Along Drainageway

Tile/Surface Water Inlet System

There are circumstances that don't permit the proper design and construction of water and sediment control basins (WASCoBs). Grassed waterways are an alternative in these situations, but are not always practical for the farm operation, including:

- small watersheds upstream of the property where there are soil erosion problems, in combination with very flat grades.
- topography along the drainageway won't allow an earthen berm to be built large enough to accommodate the necessary WASCoB runoff volumes.

In these situations, build a reasonably sized berm with a surface inlet connected to a properly sized tile draining to a proper outlet. The tile drain should be dedicated to the surface inlet and the size of the tile designed based on the peak flow from the watershed for a 1 in 2 year storm runoff event. Consider the following when building this erosion control structure.

- The maximum drop in elevation at the surface water inlet must be 1.5 m (5 ft) or less. Use the drop pipe inlet design for drops greater than 1.5 m (5 ft).
- Dedicate the tile to the surface inlet and ensure it's not larger than 250 mm (10 in.).
- Ensure there is only one surface inlet per tile line.
- Direct all runoff intercepted by the structure to a sufficient and legal outlet and provide erosion protection at the outfall.
- The maximum berm height is the height that will fully charge the tile plus 150 mm (6 in.) of freeboard.
- Build the berm with the same rigor and specifications as a WASCoB.
- Flows will generate runoff volumes in excess of the berm storage capacity regularly, so consider an emergency overflow spillway.
- The tile/surface water inlet system provides a direct path for contaminated runoff to enter surface and ground water. These inlet systems may have to be protected in the future, i.e. use of vegetated buffers around inlet systems.

Additional information regarding steeply sloping pipes can be found in the OMAFRA Publication 29, *Drainage Guide for Ontario.*

Tile/Surface Water Inlet Design Information Sheet

Use this structure for erosion control of rills and small gullies. Do **not** use for subsurface drainage purposes only.

1. Watershed area	____ ha	____ ac
2. Average grade of watershed		____ %
3. Runoff curve number from Tables 2.2 – 2.4		____
4. Peak flow from watershed for a 2 year storm from Tables 2.5-M to 2.11-M (2.5-I to 2.11-I)	____ m^3/s	____ ft^3/s
5. Vertical riser pipe		
– riser pipe type		
– riser pipe diameter from Tables 4.19-M to 4.20-M (4.19-I to 4.20-I)	____ mm	____ in.
– berm height (depth of water + freeboard (minimum 0.15 m (6 in.)))	____ m	____ ft
6. Slope of dedicated outlet tile		____ %
7. Diameter of dedicated outlet tile based on peak flow from Line (4), slope of dedicated outlet tile from Line (6) and using Table 4.18-M (Table 4.18-I), Figure 4.31 or OMAFRA Publication 29, *Drainage Guide for Ontario*	____ mm	____ in.
8. Corrugated steel outlet pipe		
– type of joint	❑ butt	❑ sleeve
– outfall type	❑ flush	❑ overhanging
– pipe diameter from Table 4.24-M (4.24-I)	____ mm	____ in.
– pipe length (minimum length + cantilever) from Table 4.24-M (4.24-I)	____ m	____ ft

- Use this erosion control structure in conjunction with grassed waterways, emergency spillways, etc.
- Do not use this structure where drop in elevation is greater than 1.5 m (5 ft) at the surface intake. For drops greater than 1.5 m (5 ft) use the drop pipe inlet design.
- Additional information regarding steeply sloping pipes can be found in the OMAFRA Publication 29, *Drainage Guide for Ontario.*

Tile/Surface Water Inlet – Example Problem #1

A farmer wants to install an erosion control system to alleviate a small gully problem that occurs across the farm. A WASCoB system or a grassed waterway can't be installed due to the flat grades. It's been decided to install a tile/surface water inlet system. Criteria pertaining to the area of farm where the erosion is occurring is stated below.

Watershed

- area = 4 ha (10 ac)
- average grade = 0.5%
- soil is hydrologic soil group B
- crops grown are corn, soybeans in straight rows (poor hydrologic condition)

Riser pipe

- small capacity riser pipe with berm

Dedicated outlet tile

- grade = 0.5%

Outfall pipe

- butt joint
- overhanging

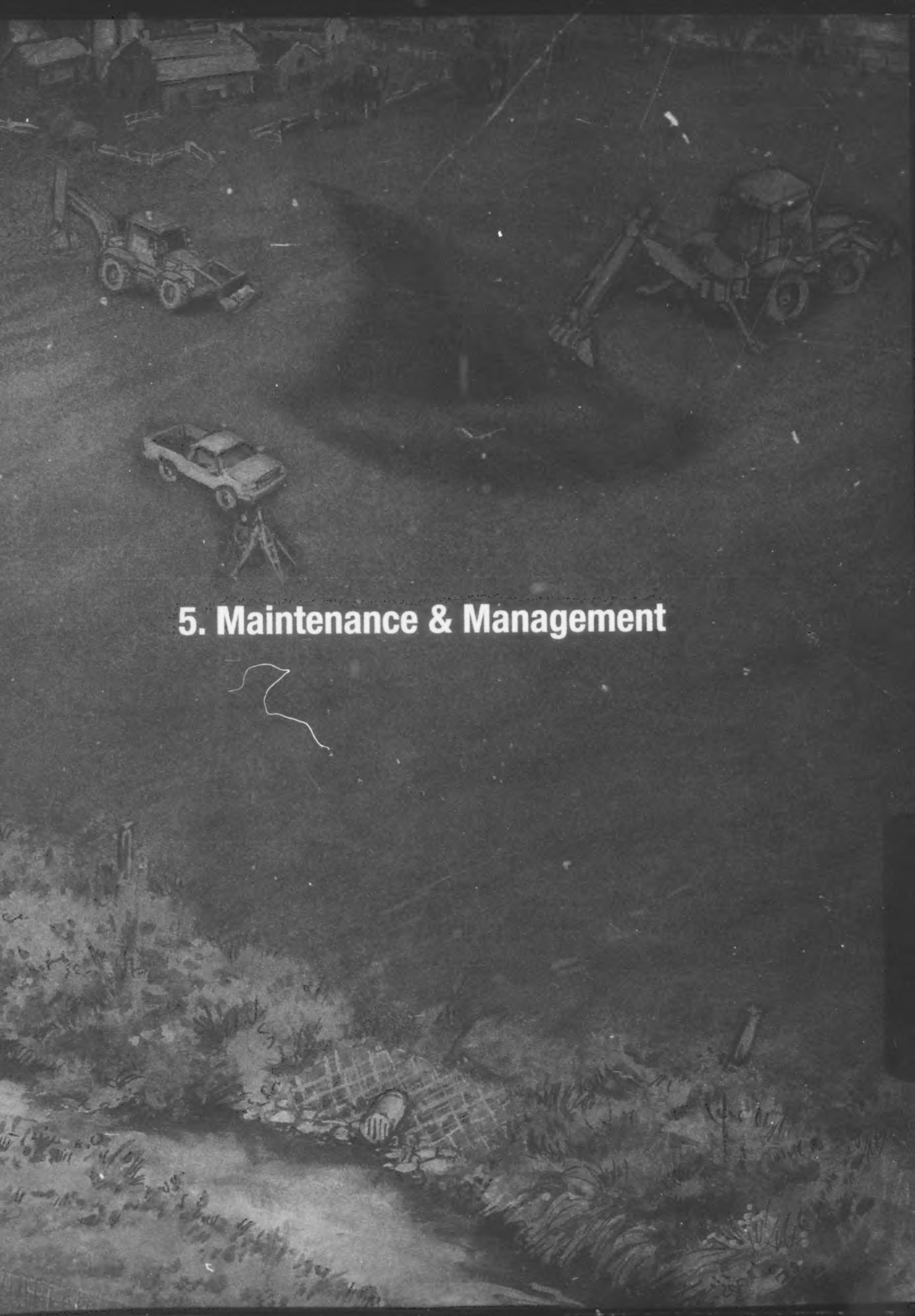
Complete the Tile/Surface Water Inlet System Design Information Sheet.

Tile/Surface Water Inlet Design Information Sheet – Example Problem #1

Use this structure for erosion control of rills and small gullies. Do **not** use for drainage purposes only.

1. Watershed area	4 ha	10 ac
2. Average grade of watershed	0.5%	
3. Runoff curve number from Tables 2.2 – 2.4	81 (use 80)	
4. Peak flow from watershed for a 2 year storm from Tables 2.5-M to 2.11-M (2.5-I to 2.11-I)	0.025 m^3/s	0.9 ft^3/s
5. Vertical riser pipe		
– riser pipe type	Small capacity riser pipe	
– riser pipe diameter from Tables 4.19-M to 4.20-M (4.19-I to 4.20-I)	150 mm	6 in.
– berm height (depth of water + freeboard (minimum 0.15 m (6 in.)))	0.75 m	2.5 ft
6. Slope of dedicated outlet tile	0.5%	
7. Diameter of dedicated outlet tile based on peak flow from Line (4), slope of dedicated outlet tile from Line (6) and using Table 4.18-M (Table 4.18-I), Figure 4.31 or OMAFRA Publication 29, *Drainage Guide for Ontario*	250 mm	10 in.
8. Corrugated steel outlet pipe		
– type of joint	☑ butt ☐ sleeve	
– outfall type	☐ flush ☑ overhanging	
– pipe diameter from Table 4.24-M (4.24-I)	250 mm	10 in.
– pipe length (minimum length + cantilever) from Table 4.24-M (4.24-I)	4.2 m	14 ft

- Use this erosion control structure in conjunction with grassed waterways, emergency spillways, etc.
- Don't use this structure where drop in elevation is greater than 1.5 m (5 ft) at the surface intake. For drops greater than 1.5 m (5 ft) use the drop pipe inlet design.
- Additional information regarding steeply sloping drainage pipes can be found in OMAFRA Publication 29, *Drainage Guide for Ontario.*



5. Maintenance & Management

5. Maintenance and Management of an Erosion Control System

This section covers the maintenance and management of erosion control structures and systems. The best designed, best constructed and best looking erosion control structure will fail without a genuine interest, desire and commitment by the owner.

The owner must first accept there is an erosion problem and decide to control it. The next step is to seek out technical assistance, information and advice from experienced and reputable sources, such as the OMAFRA office, conservation authorities, consulting engineers, erosion control and excavating contractors. A control method is then selected, followed by design and construction.

It's imperative to have the owner's involvement at all stages. The designer must involve the owner in the decision making so the owner understands and accepts the function and operation of the proposed solution. The contractor must work with the designer and the owner to achieve a satisfactory completion. Site visits during construction by the designer and owner will ensure construction is completed according to plan. The contractor must note any abnormalities encountered in soil conditions, and pass the information to the designer and owner.

When the project is complete, the owner's commitment to regular inspection, observation and maintenance is just beginning. Regular inspection and maintenance is critical to the project's long-term success. Initial damage to an erosion control structure is often quite minor, but if left unchecked, the rate of deterioration accelerates rapidly during subsequent runoff periods.

5.1 Vegetative Covers, Grassed Waterways and Buffers

- Repair and reseed any bare or eroded areas immediately to prevent or stop damage.
- Fertilize during seeding to establish a good vegetative cover. Subsequent annual applications of fertilizer are recommended to encourage and maintain a thick growth.
- Where possible, mow vegetative growth at least twice a year to encourage roots to develop and spread, creating a more erosion-resistant stand. Cut grassed waterways, in particular, more frequently during the initial two years of establishment. Ensure growth in grassed waterways doesn't reach a height that could restrict flow.
- Remove or control undesirable vegetation to prevent damage to the desired growth.
- Avoid using grassed waterways as travel lanes for cattle or farm machinery as damage can rapidly occur, especially in damp soil conditions.
- Don't plow a headland furrow parallel to a waterway – it will create a gully and defeat the purpose of the waterway.
- Take precaution with implements and machinery when working adjacent to or crossing protected areas.
- Some herbicides are extremely damaging to vegetative covers. Accidental spraying by either direct contact or runoff can quickly destroy a vegetated area especially in the early stages of development. Be sure all operators are cautioned of this danger.
- Grazing of grassed waterways and buffers is permitted, but restrict to short periods of time and only during dry soil conditions.

5.2 Drop Pipe Inlets

- Inspect the drop pipe inlet each spring for possible shifting, settling or heaving as a result of winter conditions. Problems with joint connections can be identified with piping or blow-outs.
- Check the outlet for scouring damage, which can eventually undermine the outlet pipe. Replace the pipe or improve protection as required.
- Damage at the inlet can also result in a failure. Scouring can occur due to excessive velocities and swirling action of water at the inlet. Inspect and clean grates after each storm event that results in surface runoff to prevent plugging of the inlet. Change grates that plug frequently to a different shape or size to reduce water velocity.

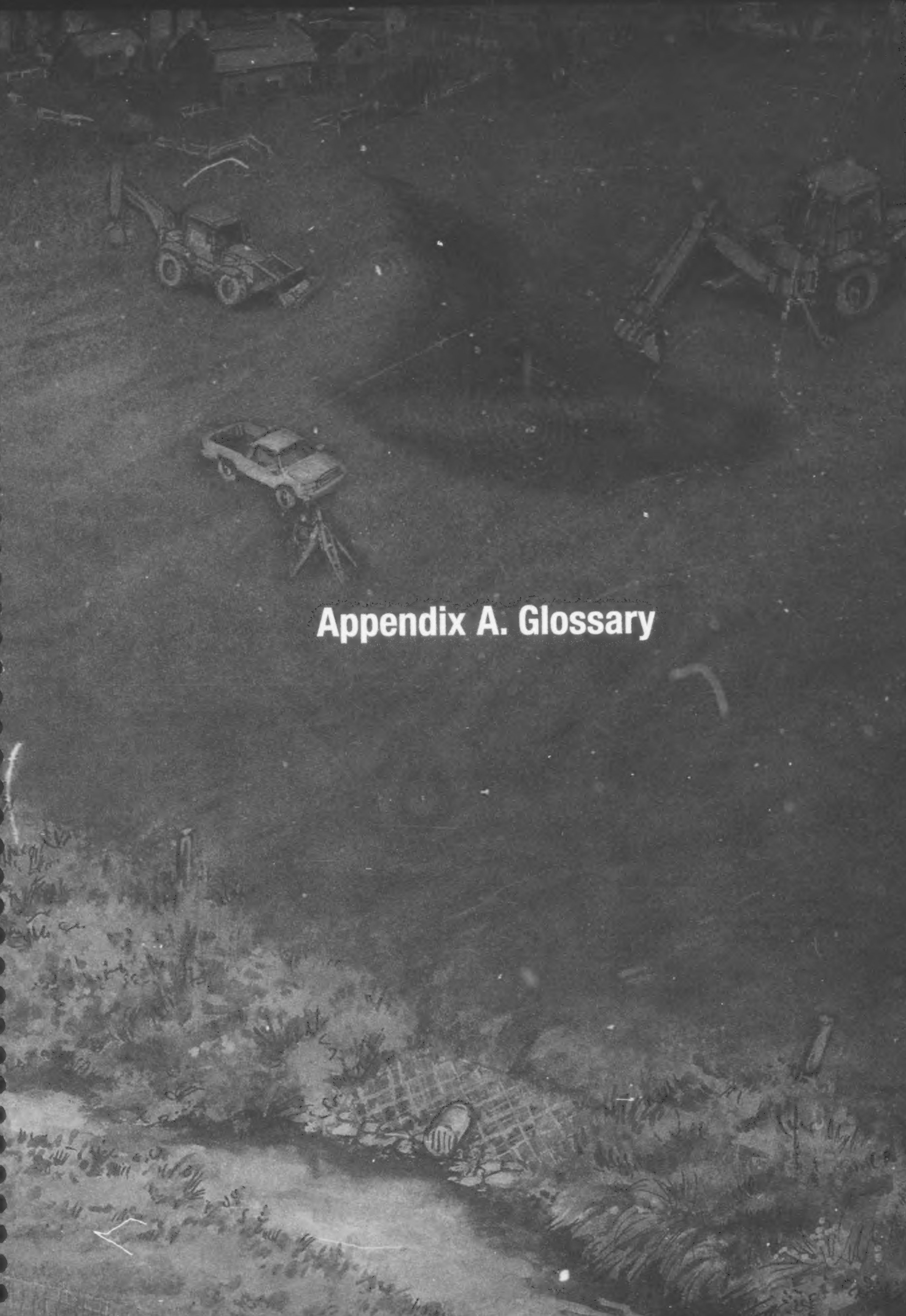
5.3 Chute Spillways and Other Soil Linings

- Failure of these systems is often caused by water finding a path under or around the structure with sufficient volume and speed to erode the soil it rests on. Look for erosion at the base and sides. Uneven settlement of the blocks or rock riprap is a good indication of a problem, even though these structures do a certain amount of self-adjusting. Regularly inspect these systems to identify and repair problems as early as possible, rather than delaying and having to undertake a replacement.
- The stone material used in rock chutes and rock riprap linings is subject to some movement in high flows. Additional material or relocation of existing material may be required quite often. If these actions are needed more frequently, the entire structure needs improvements.
- Water entering a chute spillway should do just that. Piled debris, changes in soil tillage or a wandering plow at the entrance region can alter the flow direction sufficiently at times to disrupt the intended function of the structure.

5.4 Berms and Emergency Spillways

- Identify and stop any movement or shifting of a berm.
- Repair and prevent any rodent damage.
- If a berm is tillable, use caution in selecting the type and use of tillage equipment to avoid disrupting the berm's stability.
- If the berm requires a grass cover, maintain a good stand and keep weeds under control.
- As the name suggests, emergency spillways are used infrequently during extreme runoff events that the main control structure can't handle. Some erosion can and will occur under heavy usage. Complete any repairs immediately to prevent further and usually more serious erosion during future events.
- Regularly inspect the structure to ensure the elevation of the emergency spillway is lower than the crest elevation of the berm. Look for and remove any blockages such as rubbish and silt.

Appendix A. Glossary



Appendix A

Glossary

Aerial photograph – A photograph of a ground area e.g. farm, taken from an aircraft and useful in locating tile systems, watersheds, swales, etc.

Anti-seepage collar – A steel or concrete ring around a drain pipe, sized to increase the length of flow of seepage water, and reduce seepage and ultimate washout along the pipe.

Approach – The sloped driving surface of a low level crossing constructed between the field elevation and the stream bed elevation.

Apron – The protective material placed at the bottom or toe of a slope or structure to protect the surface from erosion.

Areagraph method – A method of using charts and dots or squares to calculate a map area in square inches.

Armour rock – The rock directly resulting from the blasting of the quarry face and varies from 0.6-1.8 m (2-6 ft) in size.

Bank level crossing – A stream crossing where traffic traverses at or above the same level as the streambank. e.g. culvert.

Bed level crossing – A type of stream crossing where the traffic traverses at the same level as the streambed.

Berm – A raised area of ground that breaks the continuity of slope.

Blast rock – Rock that has been blasted from the face of a quarry and is quite variable in size.

Blind inlet – A surface water inlet constructed in low lying field areas and backfilled with porous material such as gravel to allow water to pass through to an outlet.

Borrow pit – A location from which fill material may be or has been excavated.

Broad-based terrace – A terrace with a broad base that allows farming over the whole terrace and may be built on slopes up to 8%.

Buffer strip – A permanently vegetated strip of land adjacent to a watercourse that filters runoff and stabilizes the ditch bank.

Catch basin – A basin covered by a grate and located in a low lying area to intercept surface water for transmittance to an outlet.

Channel gradient – The rise or fall of a channel base.

Channel terrace (water and sediment control basin) – A small water detention basin to pond water, usually for up to 24 hours, to reduce runoff and erosion.

Chute spillway – A steeply inclined channel for conveying water from a higher to lower level.

Clear stone – Stone that has gone through the screening plant to remove stone larger or smaller than a certain specified size.

Common law – A body of unwritten law based on long-standing usages and customs, and the court decisions and decrees recognizing, affirming and enforcing such usages and customs.

Complex topography – A topography in which slope lengths are less than 45 m (150 ft).

Contour – A line on a map or plan joining points of similar elevation.

Contour cropping – A method of cropping where tillage operations are carried out across the slope and as closely to the contours as possible.

Crest – The top or summit of a hill, pipe, etc.

Critical slope – The slope at which flow capacity does not increase with increase in slope.

Cyclone seeder – Hand turned or tractor drawn seeder that broadcasts seed or fertilizer onto the seedbed by a rotary motion.

Deceleration unit – The protective material placed at a water outlet to reduce the velocity and energy of the exit water.

Differential settlement – The uneven settlement of the ground when a drain pipe is installed under a berm.

Diversion – A channel with a supporting ridge on the lower side constructed across the slope to divert water from areas which cannot dispose of it safely.

Diversion terrace – A permanently vegetated diversion channel in combination with a supporting berm on the downslope side, laid out across the slope.

Drainage Act, 1990 – A statute governing the authorization of construction and maintenance of man-made drainage facilities.

Drainage basin – The area of land drained by a natural or artificial drainage system.

Drainage coefficient – The rate at which water is to be removed from an area.

Draw – A low lying or depressional area through which water may be conveyed.

Drop pipe inlet – An enclosed pipe structure that will intercept and carry a concentrated flow of water safely from a higher to lower elevation.

Drop structure – A structure which allows water to drop to a lower level in a controlled manner. For the purposes of this manual, drop structures may include drop pipe inlets, chute spillways or grade control structures.

Emergency spillway – A spillway to carry flood discharges exceeding a given value.

Erosion control blanket – A commercial prefabricated layer of material composed of excelsior straw or other material which may or may not contain a seed mixture.

Field terrace – A terrace constructed to shorten the field slope length and sometimes the slope itself to reduce sheet erosion.

Floodwater storage – The ponding of runoff water by constructing a berm or dam to buffer the peak flow and reduce the size of outlet structure.

Freeboard – The height from high water level to a tile drain invert.

French drain – A trench filled with pervious material, such as gravel or crushed stone, through whose voids water percolates and flows to an outlet.

Gabion – A wire mesh basket filled with stones and forming part of a larger unit used for erosion control or other purposes.

Gabion stone – A type of stone used to fill gabion baskets, in the 100-200 mm (4-8 in.) size range.

Geoxtextile – A permeable woven or non-woven synthetic fabric used to allow water to pass through while preventing fine soil particles from being washed away.

Grade control structure – A form of drop structure that will safely allow water to drop from a higher to lower elevation (1 m (3 ft) maximum).

Grassed waterway – Natural or constructed channels shaped to required dimensions and vegetated for safe disposal of runoff from a field, diversion, terrace or other structure.

Gravitational water – The water occupying the open spaces or pores in the soil that is drained off to allow air to replace it.

Gully erosion – The erosion of soil material resulting in the formation of channels in the land surface that cannot be graded out with conventional tillage equipment.

Horizon – A layer of soil approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical and biological properties such as texture, colour and structure.

Hydraulic mulch – Natural or man-made fibres capable of being mixed in a water slurry and applied under pressure through a hydraulic seeder/mulcher.

Hydraulic radius – The cross-sectional area of flow in a channel divided by the wetted perimeter of the channel.

Hydrograph – A graph of discharge or stage versus time at a given point on a stream.

Hydrologic condition – The characteristics of a soil pertaining to its ability to absorb water as a result of vegetative cover.

Hydrologic soil group – The grouping of soils by their runoff potential.

Impoundment area – The area in a floodwater storage system behind the berm that is used to pond the runoff water.

Infiltration – The entrance of water into soil through cracks, pores, etc.

Interceptor drain – A drain constructed to intercept surface water or ground water flowing from higher ground.

Intermittent flow – A water flow that is not continuous.

Isbash curve – A curve providing the size of rock riprap to be selected knowing the velocity in the channel.

Junction box – A box in which two or more drains meet.

Lateral seepage – The percolation of subsurface water through the bank, often causing an unstable bank condition.

Lateral surface flow – The concentrated surface flows of water in a lateral direction, e.g. entering the ditch over the ditch bank.

Lined waterway – A channel lined with a non-erosive protective material, e.g. rock riprap.

Loess – A silty soil type deposited by wind action with particle size between 0.01-0.05 mm.

Low flow mid-level stream and ditch crossing with culverts – A type of low level stream or ditch crossing with culverts installed to carry small sustained flows during summer months and remaining submerged during high flow periods.

Low level crossing – A type of stream crossing where traffic traverses at or near the streambed level.

Manning's equation – An equation used to estimate channel flow velocity knowing the channel roughness factor, hydraulic radius of flow and channel slope.

Minus stone – Rock riprap or stone that has passed through a certain size of screen or has exited a crusher with a certain setting.

Mulch – A covering applied to the surface of the soil to protect and enhance certain characteristics, such as water retention qualities.

Mutual agreement drain – A drain constructed under the *Drainage Act, 1990*, whereby two or more landowners have prepared a written agreement concerning the location, construction, maintenance and financing of the drain in accordance with the *Drainage Act, 1990*.

Narrow-based terrace – A terrace with a steep foreslope and backslope and normally not farmed. May be built on slopes up to 14%.

Natural watercourse – A stream of water which flows along a defined channel, with bed and banks, for a sufficient time to give it substantial existence. This may include streams that dry up periodically.

Non-woven geotextile – A geotextile produced by bonding or interlocking of fibres by mechanical, chemical or thermal means, often recognizable by the fact there is no specific pattern to the arrangement of the individual filaments.

Parabolic waterway – A waterway that is broad, shallow and saucer-shaped with an almost flat bottom and very flat side slopes.

Permeability – A soil property that indicates the relative ease with which water will flow through the soil.

Petition drain – A method of obtaining a drainage outlet under petition procedures of the *Drainage Act, 1990.*

Planimeter – An instrument used to calculate the area within any shaped boundary by moving a marker around the boundary edge.

Prescriptive right – Acquirement of the title or right to something through its open and continued use or actual possession from time immemorial or over a legally recognized or prescribed period.

Reach – A comparatively short length of a stream or channel.

Requisition drain – A method of obtaining a drainage outlet whereby a person files a requisition with the municipality requesting that an engineer be appointed to examine the area and make a report according to the provisions of the *Drainage Act, 1990.*

Return period – The average period in years between occurrences of a discharge equalling or exceeding a given value.

Rill erosion – The erosion of soil material resulting in the formation of small channels in the land surface that may be graded out with conventional tillage equipment.

Riparian owner – The person who owns the banks of a stream or other body of water.

Rock riprap – (Commonly referred to as riprap) is a permanent erosion-resistant ground cover of loose angular stone with a geotextile or granular underlining.

Roughness coefficient – A numerical measure of the frictional resistance of a surface to flow.

Runoff curve number – A runoff index for a land use under a certain treatment or practice and with known hydrologic parameters.

Scouring – A form of ditch erosion resulting in the gradual wearing away of the soil on the bank or in the channel.

Sediment – A mineral or organic matter that is transported or deposited by, or suspended in, water or other agents.

Sediment basin – A relatively large, excavated or dammed basin to intercept and store sediment.

Sediment trap – A small temporary pit or diked area provided to intercept and store sediment and is much smaller in size than a sediment basin.

Sheet erosion – The removal of a fairly uniform layer of soil from a land surface by sheet flow.

Simple topography – A topography in which slope lengths are greater than 45 m (150 ft).

Sloughing – The slow crumble and falling away of a portion of the bank into the ditch, occurring when underlying support is inadequate and/or soil structure is weakened by water seeping through the bank.

Stage – The height of water surface above a specified datum.

Statute law – A law established by a legislative body and set forth in a formal document. In its specific application, law implies prescription and enforcement by a ruling authority.

Strip cropping – A type of cropping where fields are planted in strips and the cultivated crops are alternated with buffer strips.

Swale – A shallow longitudinal depression that may be used for conveying stormwater runoff.

Terrace – An earth embankment, ridge or channel constructed across the slope at a suitable location to intercept surface runoff water, usually constructed with an acceptable lateral grade to an outlet.

Tractive force – The force due to the weight of water.

Trapezoidal waterway – A waterway with a flat, broad bottom and side slopes 4:1 or less (preferrably 10:1) to permit machinery crossing and shallower than a parabolic waterway.

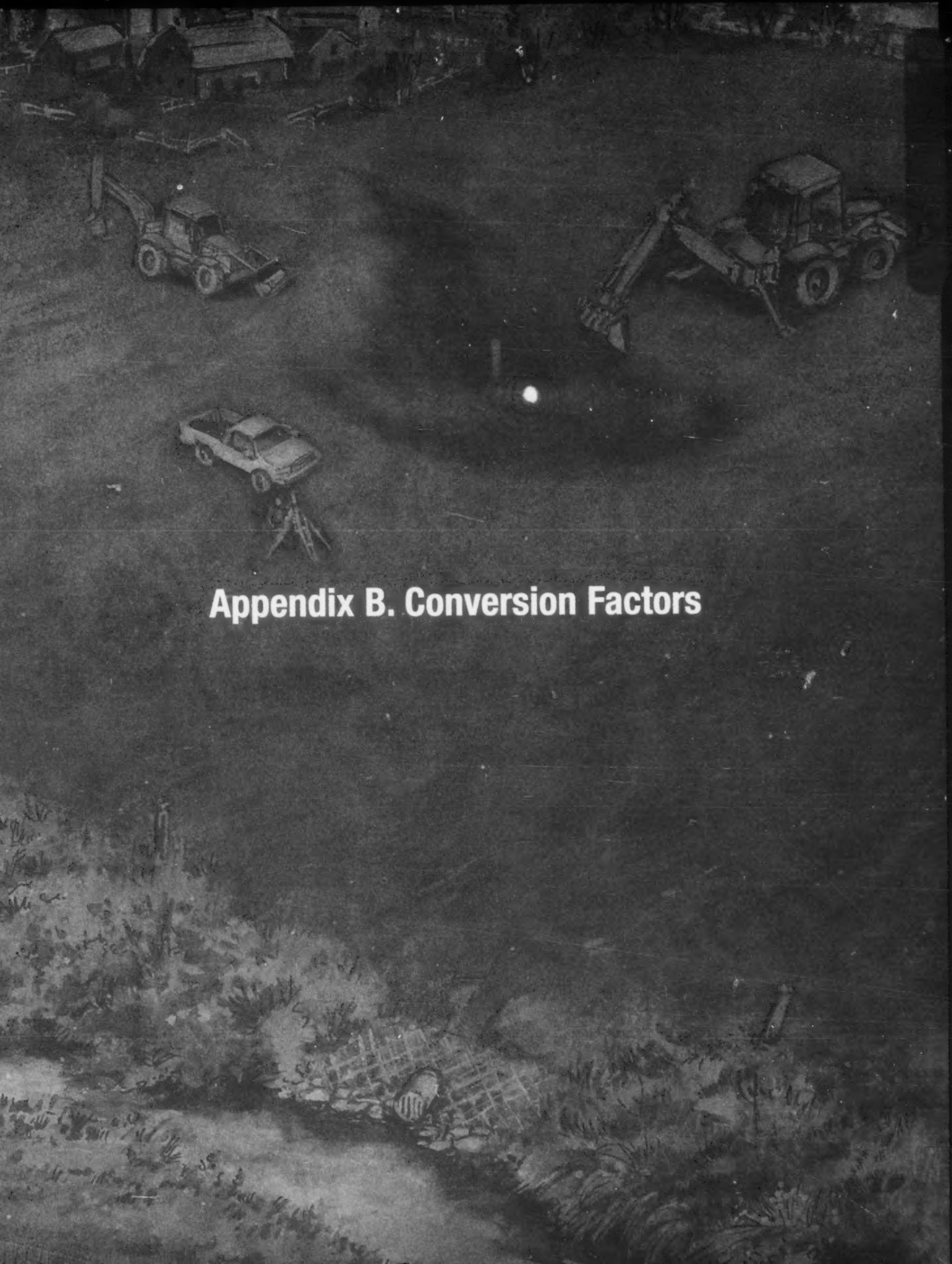
Universal Soil Loss Equation (U.S.L.E.) – An equation designed to predict the long-term soil loss caused by overland flow on a soil surface.

Washed stone – Stone that has been cleaned using water to remove all fines.

Water and sediment control basin (channel terrace) – Small water detention basin to pond water, usually for up to 24 hours, to reduce runoff and erosion.

Weir – A dam to raise the level of water, generally with a spillway over the crest, instead of gates.

Woven geotextile – Lengthwise filaments or yarns interlaced with filaments or yarns, arranged at right angles.



Appendix B. Conversion Factors

Appendix B

Conversion Factors

Imperial

1 mile = 5,280 feet
1 square foot = 144 square inches
1 square yard = 9 square feet
1 acre = 43,560 square feet
1 cubic foot = 1,728 cubic inches
1 cubic yard = 27 cubic feet
1 cubic foot water = 6.24 imperial gallons

Imperial/Metric Conversion

1 inch = 2.54 centimetres = 25.4 millimetres
1 foot = 30.48 centimetres
1 metre = 3.28 feet
1 mile = 1.6 kilometres
1 acre = 0.405 hectares
1 pound = 0.454 kilograms
1 ton = 0.907 tonnes
1 pound/acre = 1.12 kilograms/hectare
1 ton/acre = 2.24 tonnes/hectare
1 cubic yard = 0.76 cubic metres

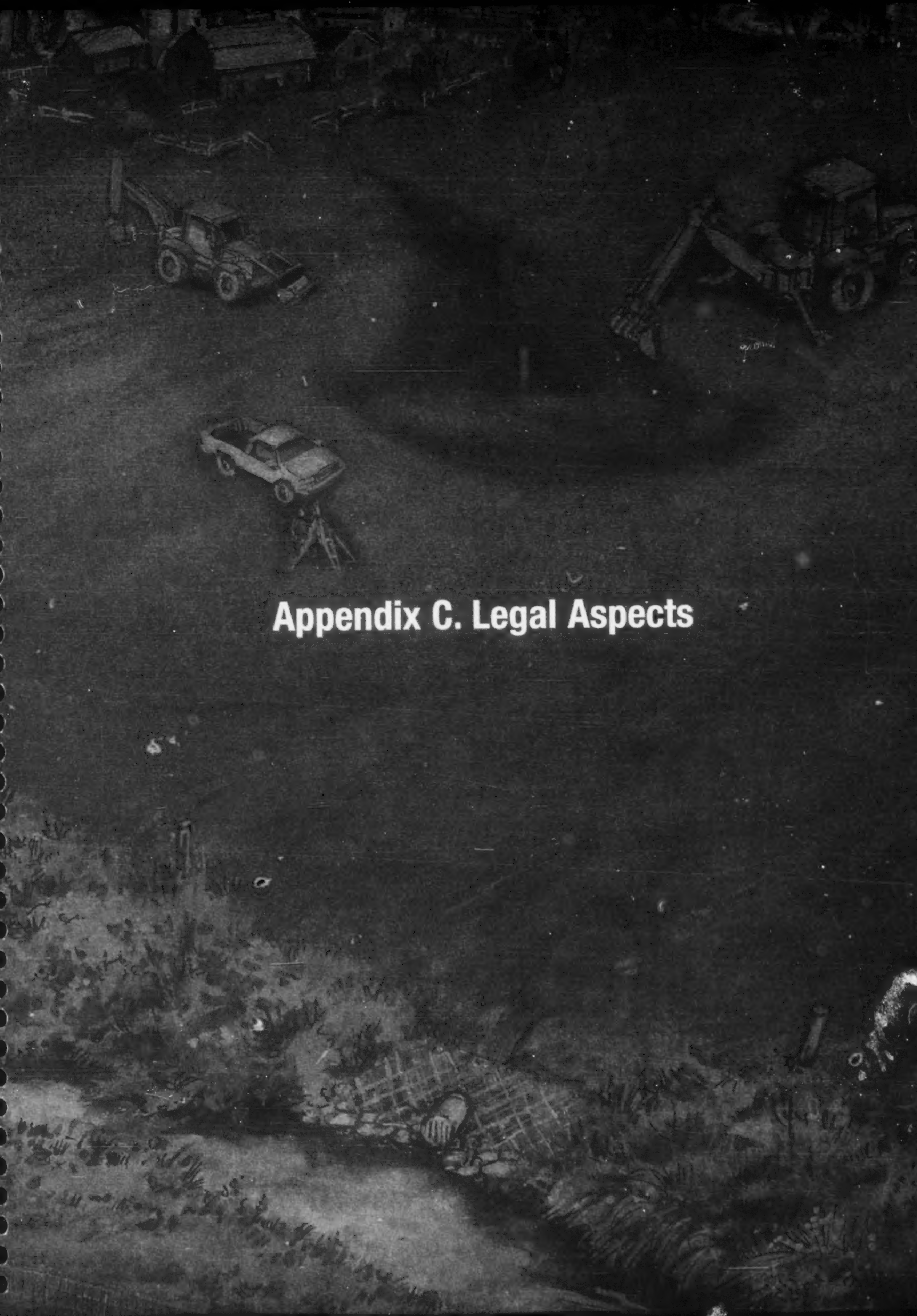
Metric

1 centimetre = 10 millimetres
1 decimetre = 10 centimetres
1 metre = 10 decimetres
1 square m = 10,000 square centimetres
1 hectare = 10,000 square metres
1 square kilometre = 100 hectares

Application Rate Conversions

pounds per acre x 1.12 = kilograms per hectare (kilogram/hectare)
tons per acre x 2.24 = tonnes per hectare (tonnes/hectare)
pounds per cubic feet x 16.018 = kilograms per cubic metre

Appendix C. Legal Aspects



Appendix C

Legal Aspects of Erosion Control Work

This section is designed to familiarize readers with the legal obligations associated with any practice that involves the artificial control of water. Where there are legal obligations, there are potential court actions. These court actions are not restricted to the property owners, and may involve contractors and anyone else providing services of any kind to the parties directly or indirectly involved.

Various levels of the law deal with water. Decisions based on one type of law may appear to be correct, but there may be another law that takes precedent over the first, potentially making the initial decision incorrect. This is true when considering Common Law as it applies to water and the various statute laws that take precedent over Common Law.

Many relevant pieces of legislation – federal, provincial and municipal – help ensure everyone involved working in or around water is giving due consideration to all users, including private landowners and the general public, as well as aquatic life. Since soil erosion control that involves structures is essentially water control, it's important to have an understanding of related legislation and guidelines.

Various penalties including fines, jail terms, profit-stripping, restitution, restoration orders, forfeiture or licence suspension may be imposed against individuals or corporations convicted under the acts noted in this appendix.

The OMAFRA Factsheet, *Drainage Legislation*, Order No. 89-166, provides information that anyone working around water and drainage should be aware of.

The following table lists the most relevant legislation that can directly affect the design, construction and maintenance of soil erosion control structural works, the government agency responsible for it, and its general purpose.

Law	Agency	General Purpose
Canada Transportation Act, S.C. 1996	Transport Canada	Controls how a drainage works is to be constructed on the lands of a railroad under the jurisdiction of the Canadian Transport Agency.
Common Law	Provincial Courts	Generally, to protect the rights of the people.
Conservation Authorities Act, R.S.O. 1990	Conservation Authorities, Ontario Ministry of Natural Resources (MNR)	To provide for the establishment of conservation authorities (CA) responsible for: conservation, restoration, development and management of natural resources other than gas, oil, coal and minerals within the jurisdiction of the CA; the prevention of floods, erosion and pollution by controlling the flow of surface waters; the regulation of building construction below the regional flood level and removal of fill; the dumping of fill in partnership with municipalities and the province of Ontario.

Law	Agency	General Purpose
Drainage Act, R.S.O. 1990	**Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)**	**To provide landowners with a procedure to resolve drainage problems through the establishment of communal drainage systems, called municipal drains. Also provides for the subsequent improvement, repair and maintenance of municipal drains by the local municipality.**
Environmental Assessment Act, R.S.O. 1990	Ontario Ministry of the Environment (MOE)	Public sector undertakings that may include water and flood protection works.
Environmental Protection Act, R.S.O. 1990	**MOE**	**To protect Ontario's land, water and air resources from pollution.**
Fisheries Act, R.S.C. 1970	Fisheries and Oceans Canada (DFO)	To conserve and protect fish, protect fish habitat and prevent pollution.
Lakes and Rivers Improvement Act, R.S.O., 1990	**MNR**	**To ensure flow and water level characteristics of lakes and rivers are not altered to the point of placing other water users at a disadvantage.**
Municipal Act, S.O. 2001	Ontario Ministry of Municipal Affairs and Housing (MMAH), Municipality	To provide for the organization and operation of municipalities in Ontario; control the types of by-laws that municipalities can adopt; regulate health, safety and other matters.
National Energy Board Act, R.S.C. 1970	**National Energy Board**	**Sets out procedures for and controls on any drainage works carried on, over, or near an underground utility.**
Navigable Water Protection Act, R.S.C. 1970	Transport Canada	Protects the public right of navigation in Canadian waters.
Nutrient Management Act, R.S.O. 2002	**OMAFRA**	**To provide for the management of materials containing nutrients in ways that will enhance protection of the natural environment and provide a sustainable future for agricultural operations and rural development.**
Ontario Water Resources Act, R.S.O. 1990	MOE	To protect the quality and quantity of Ontario's surface and ground water resources.
Pesticides Act, R.S.O. 1990	**MOE**	**To protect surface water and ground water resources from damage due to improper use of pesticides.**
Planning Act, R.S.O. 1990	MMAH, Municipality	To provide a legislative framework for land use planning; establish Provincial Policy Statements setting provincial policy for the planning of natural resources and growth management; authorize municipalities to establish Official Plans, zoning by-laws, site plan control, interim control by-laws; temporary use by-laws, subdivision control.
Public Lands Act, R.S.O. 1990	**MNR**	**Sets out the rules governing the administration of Crown Land (not under Federal control e.g. national parks, Indian reserves, canals etc.). The beds of most lakes, rivers and streams are legally provincial Crown Land in Ontario.**
Public Transportation and Highway Improvement Act, R.S.O. 1990	Ministry of Transportation (MTO)	Generally, sets out procedures and controls for the construction, maintenance, drainage, construction/ development adjacent to highways etc. in Ontario.
Railway Safety Act, R.S.C. 1970	**Transport Canada**	**To promote and provide for the safety of the public and personnel, and the protection of property and the environment, in the operation of railways.**
Species at Risk Act (SARA), 2002	DFO	To protect many aquatic species including fish, reptiles, marine mammals and molluscs.

Note: The information provided in this table and within this document is not to be used by persons with drainage or water problems as a substitute for competent legal advice. The application of the law usually depends upon the circumstances of each case and laws may be changed by court decisions or legislation.

Common Law

Common Law forms the basis of the legal system. It always applies, unless it is specifically altered by a statute passed by the provincial or federal governments. Common Law disputes are arguments between landowners, and if they can't be mutually resolved, final solutions can be determined through the courts. More information is found in the OMAFRA Factsheet, *Top 10 Common Law Drainage Problems Between Rural Neighbours*, Order No. 98-015.

Statute Laws

Statute laws are established by the legislature or parliament in order to protect and meet the needs of the people. The *Drainage Act, R.S.O. 1990, Tile Drainage Act, R.S.O. 1990, Water Resources Act, R.S.O. 1990, and Highway Traffic Act, R.S.O. 1990,* are examples of statutes.

Drainage Legislation

Profitable returns from farmland depend on effective drainage. A farmer may be convinced of the need for improved drainage but complications such as getting access to a proper outlet or securing adequate funding may arise when undertaking such work often delays action. The provincial government has created laws to assist farmers in carrying out drainage projects. Among the laws are:

- *The Drainage Act, R.S.O. 1990* – Within this act, the three types of procedures established for construction of drains involving more than one landowner are the mutual agreement, requisition and petition procedures. Contractors doing work to control soil erosion are encouraged to make use of the mutual agreement when the structure can be defined as a drainage work under the *Drainage Act, R.S.O. 1990,* and it requires the cooperation of two or more landowners.

  Mutual agreements are recognized to have a limited application and should be reserved for smaller projects. The limits result from the fact that, although the agreement might state how the project is to be constructed and maintained, the only method of forcing compliance with the agreement is through the courts. Alternately other methods of drain construction under the act are controlled by the municipal government, the costs are collected as taxes, and landowners are compelled to cooperate.

  Any grants outside of the *Drainage Act, R.S.O. 1990* are targeted for erosion control works rather than drainage works. A private drainage work may be eligible for grants on the portion of the work deemed to be for erosion control rather than for the full grant on the total cost of the works.

  Mutual agreement forms are available from Municipal World, Box 399, St. Thomas, Ontario N5P 3V3.

- *The Tile Drainage Act, R.S.O. 1990* – Provides loans to agricultural property owners to assist them in financing tile drainage projects.

- *The Agricultural Tile Drainage Installation Act, R.S.O. 1990* – Regulates the installation of tile drainage, e.g. contractor, business, machine licensing and quality of work.

Nutrient Management Act

Enacted in June 2002, the *Nutrient Management Act, 2002* as amended, is intended to control nutrients on farms so they don't enter surface water or infiltrate ground water. It's also designed to control pollution from biosolids (i.e. sludge from sewage treatment plants) when they are spread on land. The Act is administered by both the Ministry of the Environment and the Ministry of Agriculture, Food and Rural Affairs.

A general regulation (O.Reg. 267/03, as amended) has been passed under the *Nutrient Management Act, 2002* to set out requirements regarding the application (and phasing-in) of the Act; the development and approval of nutrient management strategies and plans; and standards respecting land application, facility siting and construction, and sampling and analysis.

Environmental Protection Act

The main source of environmental regulation in Ontario is the *Environmental Protection Act, R.S.O. 1990.* It provides for the control of air, water and land pollution and its basic structure is to prohibit the emission or discharge of a broad range of contaminants that cause or are likely to cause an "adverse effect" to the natural environment. Prohibited adverse effects include harm or material discomfort to persons; the impairment of the safety of persons; injury or damage to property or to plant or animal life; loss of enjoyment of normal use of property; and interference with the normal conduct of business.

Ontario Water Resources Act

The purpose of the *Ontario Water Resources Act, R.S.O. 1990,* is to preserve the supply and purity of the natural waters. The Act is administered by the Ministry of the Environment. There could be situations where the following sections of the Act would apply to a project.

Every municipality or person that discharges or deposits material of any kind into any water body or watercourse that impairs the quality of that water is guilty of an offence. When a municipality or person pollutes a water body through discharging material into it that is not in the normal course of events, the municipality or person must notify the minister.

The Environmental Assessment Act

The purpose of the *Environmental Assessment Act, R.S.O. 1990,* as stated in the Act, is the betterment of the people of the whole or any part of Ontario by providing for the protection, conservation and wise management in Ontario of the environment. It is administered by the Ministry of the Environment.

An environmental assessment, if required to be submitted for a project, would include: the purpose of the undertaking, rationale for the undertaking considering alternatives, description of environmental effects, and an evaluation of the advantages and disadvantages. The cost of the environmental assessment is paid by the proponents (requested for private projects).

Contact the Ontario Ministry of the Environment at *www.ene.gov.on.ca* for further information.

The Municipal Act

The *Municipal Act, R.S.O. 2001*, provides the authority to the local council to pass various by-laws that may affect the actions of the landowners with respect to drainage. Some of the key areas of interest related to drainage include:

- authorization for council to pass by-laws to enter into agreements concerning joint works and undertakings
- power to pass by-law providing for joint management of water and sewage systems
- power to pass by-law for constructing or stopping up drains and watercourses
- passing of by-laws for prohibiting the obstruction of drains or watercourses
- by-law for filling up, draining of any grounds, and repairing private drains
- by-laws on drainage or sewage regulations
- drain connections
- by-laws on regulating construction of trenches
- by-laws for extension of sewers into adjoining municipality
- by-laws on regulating discharges into drains or sewers
- by-laws for prohibiting obstruction of ditches or culverts on highways

The Lakes and Rivers Improvement Act

The *Lakes and Rivers Improvement Act, R.S.O. 1990*, gives the Ministry of Natural Resources the mandate to manage water-related activities, particularly in the areas outside the jurisdiction of conservation authorities. The purpose of the Act is to manage the use of the waters of the lakes and rivers of Ontario, to regulate improvements in them, and to provide for:

- preserving public rights in or over water
- protecting the interests of riparian owners
- management of fish, wildlife and other natural resources dependent on such waters
- preserving natural amenities
- ensuring the suitability of the location and nature of improvements

The *Lakes and Rivers Improvement Act, R.S.O. 1990*, applies to both private and public lands covered by water and therefore may be applied to any drain that uses a natural stream as a part or whole of its length and is applicable to any drains that outlet into a natural stream or lake. A work permit is required for any activities that increases the flow, holds back or diverts water.

Further information on this Act, the MNR Factsheet Working Around Water? – What you should know about the *Lakes and Rivers Improvement Act, R.S.O. 1990*, can be seen online at *www.mnr.gov.on.ca/MNR/csb/news/crown4.html*

Further information can be obtained by contacting the local MNR office or visit *www.mnr.gov.on.ca/MNR/water/links.html*

Conservation Authorities Act – Generic Regulations

Conservation authorities are responsible for conserving, restoring, developing and managing natural resources within their jurisdiction. The new Generic Regulation (Ontario Regulation 97/04) replaces the old *Fill, Construction and Alteration to Waterways* regulations, and fulfils the same general purpose of ensuring public safety and preventing property damage and social disruption, due to natural hazards such as flooding and erosion. The conservation authority implements the regulation by issuing permits for works in or near watercourses, valleys, wetlands or shorelines, when required. The types of activities regulated and the process for obtaining a permit have not changed significantly. As before, property owners must obtain permission from the conservation authority before beginning any development, site alteration, construction or placement of fill within the regulated area. Permits are also required for any wetland interference, or for altering, straightening, diverting or interfering in any way with the existing channel of a creek, stream or river.

Contact the local conservation authority for more information or Conservation Ontario at *www.conservation-ontario.on.ca*

Fisheries Act

The *Fisheries Act, R.S.C., 1970,* is federal legislation dealing with three fundamental subject matters – the proper management and control of the fisheries, the conservation and protection of fish and the protection of fish habitat, and the prevention of pollution.

The federal *Fisheries Act, R.S.C., 1970,* provides for the protection of fish habitat, which is defined as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly and indirectly to carry out their life processes".

Under the *Fisheries Act, R.S.C., 1970,* no one may carry out any work or undertaking that results in the harmful alteration, disruption or destruction (HADD) of fish habitat, unless authorized by the Minister of Fisheries and Oceans Canada. The Act also states that no one is permitted to deposit a deleterious (harmful) substance into water containing fish.

When planning a project near water, consider the following:

- Will the project affect fish habitat?
- Could it affect ground water discharge or recharge areas?
- Could there be downstream or upstream effects?
- Will sand, gravel or stone be added or removed from the water body?
- Is a culvert, dam or bridge to be installed or replaced?
- Is a dam or reservoir being created?

Fisheries and Oceans Canada may become aware of a project through a direct request or through a referral from a provincial agency or other organization. Fisheries and Oceans Canada will review the information to determine if there is fish habitat affected by the project.

When considering a project, start by contacting one of the following agencies in the area:

- Contract the local conservation authority (CA) office if property is in a watershed that has a CA.
- If there is no CA in the area – contact the local Ontario Ministry of Natural Resources (MNR) office.
- If the property fronts onto the Rideau Canal, Trent-Severn Waterway or other federal lands – contact the local Parks Canada Agency (PCA) office.

To find out more information about the *Fisheries Act, R.S.C. 1970*, visit *www.dfo-mpo.gc.ca/oceans-habitat*

Class Authorization System for Southern Ontario

Conservation authorities, Fisheries and Oceans Canada, Parks Canada and MNR have developed a Class Authorization System to help streamline the process of reviewing fisheries concerns for municipal drain maintenance.

Since there are many municipal drains being maintained across Ontario, this could be a very time consuming process and cause delays for landowners needing improved drainage, as well as for drainage superintendents trying to coordinate their work schedules. The Class Authorization System cuts through much of that red tape. It allows municipalities, through their drainage superintendents, to complete work such as bottom clean outs, on less sensitive drains. Drainage superintendents can save time on planning since they will know in advance what kind of work and timing is required for certain maintenance projects. The Class Authorization System also helps municipalities and drainage superintendents identify projects that might need a more in-depth examination.

For habitat management purposes, the Class Authorization System classifies municipal drains according to their flow characteristics, water temperatures, fish species present and time since the last full clean out.

Drainage superintendents, conservation authorities and other agencies are classifying all municipal drains in Ontario with the goal of putting this information onto maps to help municipalities and their drainage superintendents identify the correct steps in maintaining a particular drain. As characteristics of the drains change, the new information is used to update the classification.

Contact the local drainage superintendent or conservation authority for more details.
Fisheries and Oceans Canada has a set of factsheets for more information, available on-line at *www.dfo-mpo.gc.ca/oceans-habitat*

Species at Risk Act (SARA)

A growing number of wildlife species in Canada face a very real – and in many cases, immediate – threat of extinction. Some of these species are important to industries such as Canada's fisheries. Some of them are the last of their kind in the world. All of them have an essential role to play in the

environments where they live. The *Species at Risk Act (SARA), 2002,* was created to protect many aquatic species from becoming extinct – including fish, reptiles, marine mammals and molluscs – in two ways:

- providing for the recovery of species at risk due to human activity
- ensuring through sound management that species of special concern don't become endangered or threatened

SARA became law in June 2003, and enforceable in June 2004. It's important to know about SARA, when installing a culvert, starting a new dredging operation or developing a hydroelectric power dam. It's the responsibility of individuals to ensure any projects undertaken comply with SARA. The process for doing so remains as it always has been. Any works – from marinas to bridges – must be reviewed by local, provincial or federal authorities and authorized through formal approvals and permits. Apart from making sure the work is in compliance with the Act, active steps can be taken to protect the habitat of species at risk.

To find out more about species at risk, contact appropriate municipal, provincial and federal government representatives, or view the SARA online at *www.dfo-mpo.gc.ca*

Public Transportation and Highway Improvement Act

Construction on or adjacent to a provincial highway may require a permit from the Ministry of Transportation (MTO). MTO issues permits under the *Public Transportation and Highway Improvement Act, R.S.O. 1990,* and administration of the permits is the responsibility of the Corridor Management Office. The Corridor Management Office reviews applications from developers, municipalities, utility companies and the general public for adherence to policies and impacts on the highway system, resolving conflicts, issuing permits and enforcement of violation of policies.

For the purpose of this guideline, typical highway improvements may include – but aren't limited to – drainage works, landscaping, culverts for walkways, storm sewers, stream diversions, watermains, sanitary sewers, underground cable or hydro lines, gas lines, telephone cables, television cable and field surveys.

Visit *www.mto.gov.on.ca/english/engineering/management/corridor/encroach.htm* for more information.

MTO has developed a number of documents and tools to address drainage and hydrology considerations in highway design and corridor management. These tools are intended to assist consultants, design engineers, drainage professionals and MTO staff to identify MTO drainage policy, MTO design procedures and MTO requirements. Visit *www.mto.gov.on.ca/english/engineering/drainage/* for more information.

Canada Transportation Act

Over the last 15 years, the federal government has progressively de-regulated the rail industry. In 1996, the federal government passed the *Canada Transportation Act* (CTA). A review of the Act is legislated to occur every four years. Where a drainage works is to be constructed on the lands of a railroad under the jurisdiction of the Canadian Transport Agency, individuals must contact the Transport Canada Ontario Regional office:

4900 Yonge Street, Suite 300
North York, ON M2N 6A5
Telephone: 416-973-9820
Fax: 416-973-9907

Make this contact early in the process in order to determine whether or not a formal approval is required. Visit *www.tc.gc.ca/acts-regulations/GENERAL* for more information.

National Energy Board Act

The National Energy Board regulates activities on or adjacent to pipeline rights of way under Board jurisdiction in the interests of the protection of property, the environment, the safety of the public and the pipeline company's employees.

Pipeline companies are subject to the National Energy Board under the *National Energy Board Act, R.S.C. 1970.* To ensure safety, crossing of pipelines by drainage works may be carried out in accordance with the *National Energy Board Act, R.S.C. 1970.* Any work over or near an underground utility must receive approval from the company, prior to commencing. Visit the National Energy Board website at www.one.gc.ca for more information.

Always call before digging. Regardless of location and what regulations may apply, always call One-Call or individual companies to ensure work will not interfere with buried facilities.

Permit Requirements

Permits may be required under many of the statutes. The following lists the agencies responsible for issuing permits under the various statutes.

Ministry of the Environment

Permits may be required for the use of some herbicides on drains. Obtain permits from the MOE, regional office or the pesticides control section, 135 St. Clair Avenue West, Toronto, Ontario M4V 1P5, telephone 416-325-4000 or 1-800-565-4923.

If the work includes a diversion channel or dam, a permit to take water may be required from the Ministry of the Environment. A permit to take water is required when 50,000 litres of water is taken into storage or diverted in a 24-hour period.

A permit or certificate of approval is required from MOE whenever a contaminant is discharged from wastewater outfall. Where the discharge is into a body of water, an approval is required under the *Ontario Water Resources Act, R.S.O. 1990,* which regulates both the taking of water for human or industrial use, and the discharge of wastes and storm water directly into a river or lake. Before a permit or certificate of approval will be issued, government agencies generally require detailed plans describing the nature of the discharge source and the manner in which the level or concentration of contaminants in the discharge will be minimized.

The *Clean Water Act, S.O. 2006,* will ensure communities are able to identify potential risks to their supply of drinking water and take action to reduce or eliminate these risks. Municipalities, conservation authorities, landowners, farmers, industry, community groups and the public all work together to meet common goals. The effect of this legislation on soil erosion and drainage is still not determined.

Contact the Ontario Ministry of the Environment at *www.ene.gov.on.ca* for further information.

Conservation Authority

As part of the new Generic Regulation, permits are required from the conservation authority before beginning any development, site alteration, construction or placement of fill within the regulated area. Permits are also required for any wetland interference, or for altering, straightening, diverting or interfering in any way with the existing channel of a creek, stream or river.

This new regulation fulfils the purpose of ensuring public safety and preventing property damage and social disruption, due to natural hazards such as flooding and erosion. The types of activities regulated and the process for obtaining a permit have not changed significantly.

Contact the local conservation authority for more information or Conservation Ontario at *www.conservation-ontario.on.ca*

Ministry of Natural Resources

The Ministry of Natural Resources works with many partners to develop and implement sustainable water management programs through legislation. A permit from the Ministry of Natural Resources may be required under the following acts:

- *Lakes and Rivers Improvement Act, R.S.O. 1990*
- *Public Lands Act, R.S.O. 1990*
- *Fisheries Act, R.S.C. 1970*
- for work on:
  - o bridges (new or repair)
  - o crown land
  - o private land where the drainage area is greater than 5 km^2
  - o culverts
  - o stream, rivers, creeks or lakes
  - o open municipal drains
  - o private land where the length is less than 20 m and drainage area is greater than 5 km^2, or the length is greater than 20 m
  - o municipal land where the length is greater than 20 m

Other

- for work on:
  - o dams, channelizations, diversions, in-stream ponds and by-pass ponds on all lands
  - o cables or pipelines into lakes or river beds (where excavation required), for commercial or industrial activity on all lands

Permits are not required for agricultural drains and trenching to install heat loops, water intakes and service cables for private residences.

Public Lands Act

A work permit is a document issued by the Ministry of Natural Resources under authority of Section 14 of the *Public Lands Act, R.S.O. 1990,* to authorize specific activities and works on public lands and shore lands. A work permit is required to:

- fill shore lands such as creating a beach and constructing shoreline protection works (e.g. break wall, groyne, seawall)

- dredge shore lands such as:
  - o creating a boat slip, boating channel or swimming area
  - o installing a water line, heat loop or cable for commercial use (i.e. marina, resort or large scale development)
  - o removal of rocks/boulders from shore lands or the bottom of a lake or stream
- construct a dock or boathouse where the total surface area of the supporting structure (e.g. pipes, cribs) placed on the bed of the water body exceeds 15 m^2 (161.5 ft^2)
- construct a water crossing (e.g. bridge, culvert and causeway) on public land, except where constructed under the authority of the *Crown Forest Sustainability Act, 1994*
- remove aquatic vegetation

Some types of activities do not require a work permit including:

- cantilever docks where the footings are located off the shore lands
- floating docks and floating boathouses
- docks or boathouses where the total surface area of the supporting structure (e.g. pipes, cribs) placed on the bed of the water body is less than 15 m^2 (161.5 ft^2)
- removal of an old dock or boathouse
- ice fishing huts
- installation of a water line, submarine cable or heat loop for private use
- work carried out on federal lands

For detailed information on the Ministry's requirements for work permits, refer to Policy PL 3.03.04 – *Public Lands Act, R.S.O. 1990,* Section 14, Work Permits.

Fisheries Act

In areas where conservation authorities don't exist, contact the local MNR office for authorization requirements. Visit *www.mnr.gov.on.ca/MNR/water/links.html* for more information.

Ministry of Transportation

All development and highway improvements are controlled by MTO permits under authority of the *Public Transportation and Highway Improvement Act, R.S.O. 1990,* (PTHIA). Where appropriate, a legal agreement, executed by the Minister or a delegated authority, may be required in addition to the permit. Anyone planning to construct on or adjacent to a provincial highway may require a permit from the Ministry of Transportation (MTO). MTO issues permits under the *Public Transportation and Highway Improvement Act, R.S.O. 1990,* and administration of the permits is the responsibility of the Corridor Management Office. The Corridor Management Office reviews applications from developers, municipalities, utility companies and the general public for adherence to policies and impacts on the highway system, resolving conflicts, issuing permits and enforcement of violation of policies. For the purpose of this guideline, typical highway improvements may include – but are not limited to – drainage works, landscaping, culverts for walkways, storm sewers, stream diversions, water mains, sanitary sewers, underground cable or hydro lines, gas lines, telephone cables, television cable and field surveys.

For drainage improvements works that encroach on MTO regulated lands, a permit will likely be required. Visit *www.mto.gov.on.ca* for more information.

Utilities

If a telephone line, gas or oil pipeline, or other utility is to be crossed, it's essential they be contacted early in the procedure so decisions can be made relative to design of the drain on relocation of the facilities. If relocation is necessary, the time involved could be as much as a year where new easements have to be obtained. Approval from the company may be required prior to commencing.

"Always call before you dig." Regardless of location and what regulations may apply, always call One-Call or individual companies to ensure work will not interfere with buried facilities.

Common Law – The Right to Drain Land

The following information is taken from an actual court case settled in January of 1983. This review is a condensed version of the actual decisions and is meant to demonstrate the type of results that may be expected from an action dealing with the common law as it applies to water.

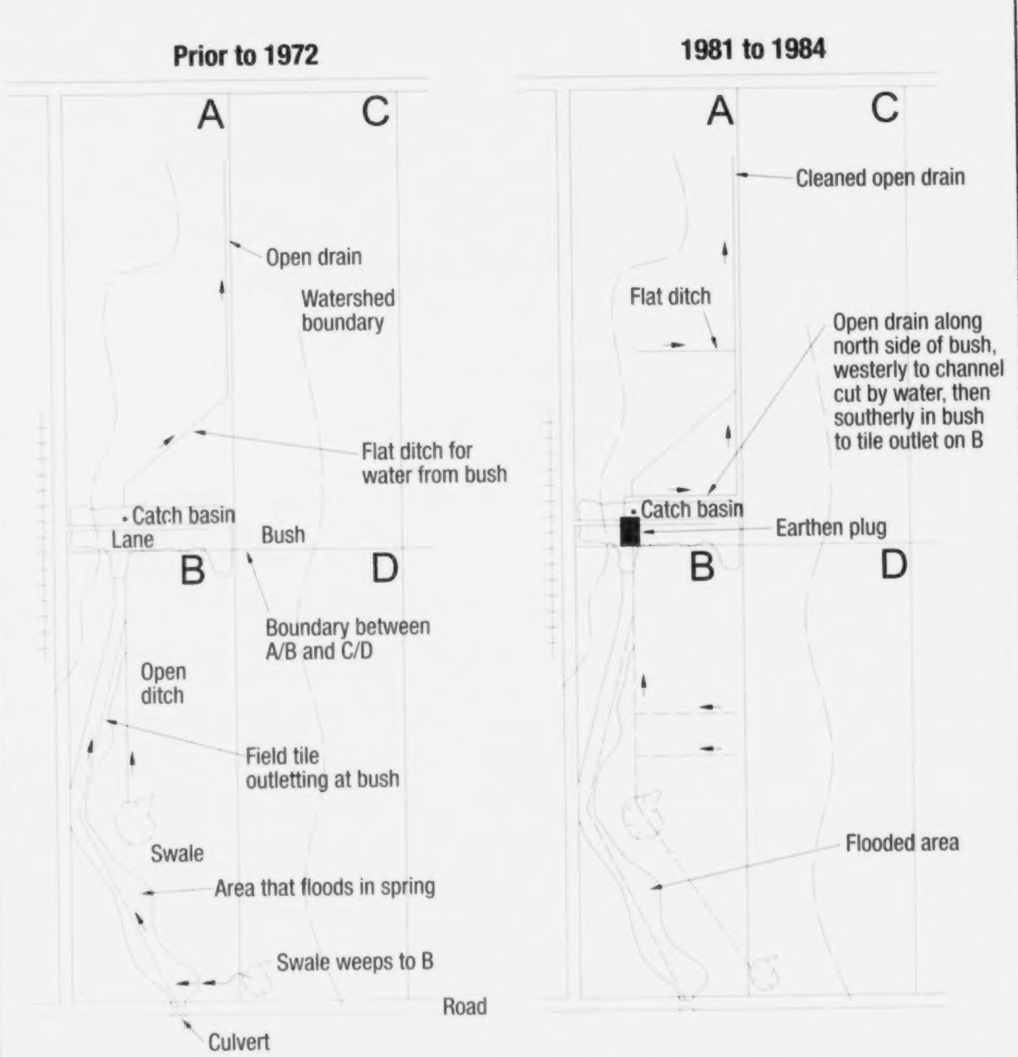
The judge's decision appears to reinforce the following statements that have been made with respect to the common law.

> "In Ontario no right of drainage of mere surface water exists. A lower land owner owes no servitude to an upper land owner to receive the natural drainage unless a prescriptive right has been acquired."

> "The right to drain one's land by ditches is undoubted providing that the water is carried thereby to a sufficient and proper outlet so that the water which may be discharged there from will do no harm to other proprietors. Anything short of this must be regarded as negligence."

> "Where what was once a natural watercourse becomes part of an artificial drainage system, it is no longer entitled to particular immunity under the law, over the parts which are purely artificial. The whole must operate so as to discharge the waters which it gathers at a proper and sufficient outlet."

Figure C.1 provides the physical description of the area as it was to have existed prior to 1972 and secondly, as it appeared just prior to the trial.



Plan of physical areas involved in court case as existing prior to 1972, and from 1981 to 1984

Figure C.1. Common Law Plan

The watershed where all the controversy took place included parts of lots A, B, C and D. The artificial drainage work is primarily confined to lots A and B. The natural flow travels from B to A. An open ditch drained the swale in B toward A, the tile had been installed through the low run in B. This also drained toward A. The outlet for this tile was in the ditch at a point about 75-90 m (250-300 ft) below the property line between B and A.

In the spring period water seeped from B to A through the bush and over the laneway. This water was intercepted by a catch basin feeding into a tile with any overflow being directed through a shallow ditch. The outlet for these works was through a ditch between lots A and C. Further drainage developments took place as follows. The swales in properties B and D were connected with tile drains. The open ditch that drained the swale in B was replaced with a tile that was dumped about 6 m (20 ft) from the property line between B and A.

It was after this work that an outlet was eroded across the woodlot and the laneway. On property A, the catch basin and the shallow ditch could not contain the flows and flooding resulted. To remedy the problem, the owners of A and B verbally agreed to cooperate for the financing of the ditch work as is shown on the diagram. The construction was to consist of two new ditches and the deepening of some existing ditch on A. After the work was done, B declined to pay.

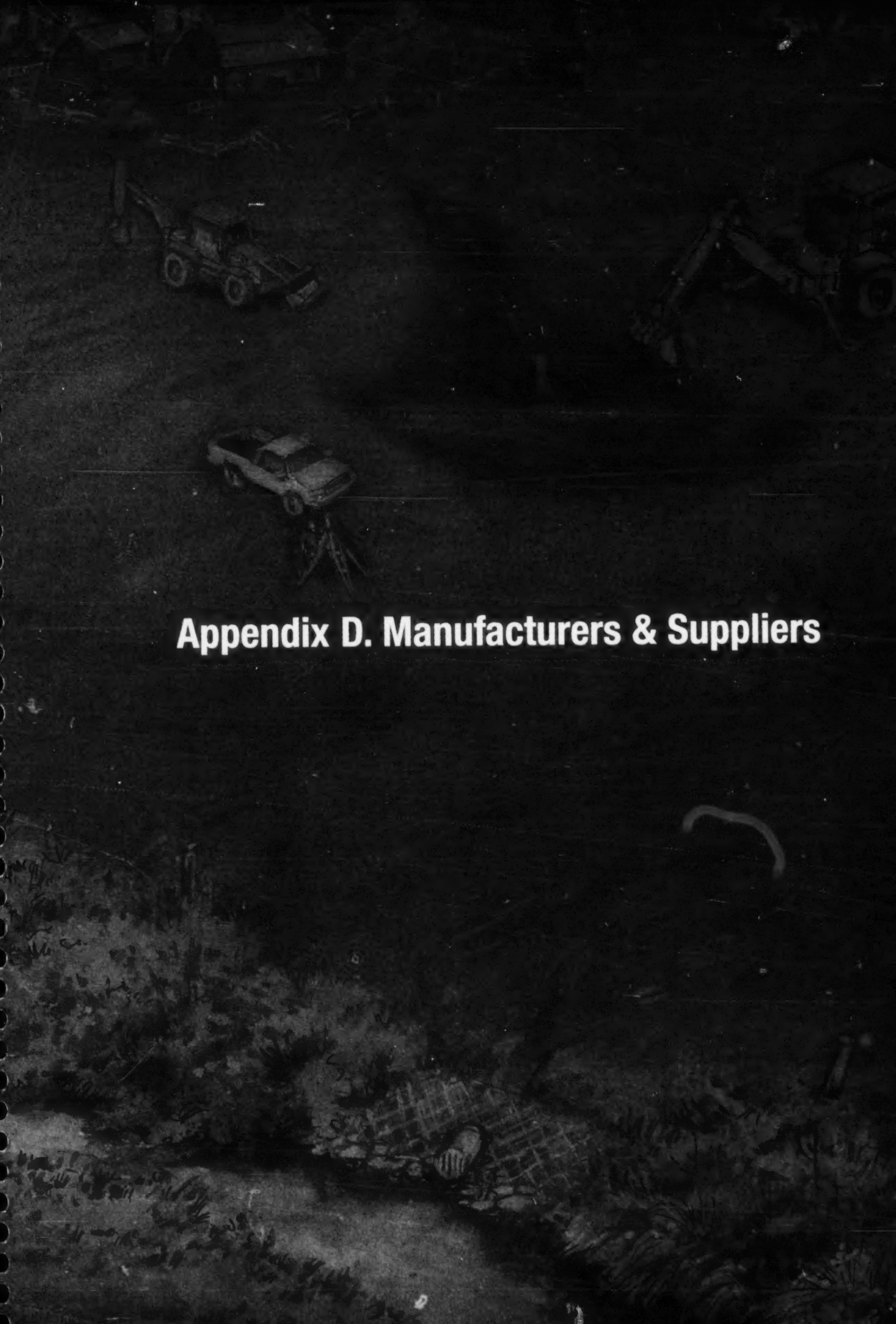
A did not believe the channel was a natural watercourse, subsequently constructed a dam and refused to accept the water from B.

The judge found from the evidence that the flow of water had increased since 1972, the water had been gathered from several sources and had been discharged upon lower property in one location – the tile outlet near the property boundary at the bush. It was recognized that a prescriptive right had been obtained for the volume of water which came to the lower property by various routes prior to the tile installation of 1972. The judge proposed a covered outlet of adequate cross-section as provided by plans and specifications of the engineers who testified at the trial, at the expense of the upper land owner. In return, the lower land owner would remove the obstruction blocking the present tile outlet from the owners at property A. Further, the owners of A received some recompense for loss of land use, construction costs and breach of verbal contract plus interest since mid 1981.

What Does the Case Mean to the Drainage Industry?

- The collecting of surface waters (or subsurface waters) and discharge in one location by an upper owner on lower lands renders the upper land owner liable for damages and/or other costs resulting from the action.
- While in this action the drainage contractor or other agencies who may have been involved in the pre-1972 decision to improve the drainage of the upper lands have not been implicated, they have every possibility of becoming involved.
- Advice on the appropriateness for surface or subsurface waters when no suitable outlet such as a natural watercourse or municipal drain exists can't be given without fear of liability.
- The common law statements stated at the start of this article are basic, always apply and always govern except insofar as the common law may be varied or added to by statute.

Appendix D. Manufacturers & Suppliers



Appendix D

Manufacturers and Suppliers

The following is a partial list of manufacturers and suppliers of erosion control and related products, based on information available at the time of manual production. References to particular products or suppliers is not endorsement.

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Acton Precast Concrete Limited 8949 Wellington 50 Rd. Acton, ON L7J 2L8 519-853-1529 *www.actonprecast.com*		X				X												
Albarrie Canada Limited 85 Morrow Rd. Barrie, ON L4N 3V7 705-737-0551 *www.alberrie.com*													X					
Amoco Fabrics Ltd. 1423 Cameron St. Hawkesbury, ON K6A 2B9 613-632-4191													X					
Anco Chemical Inc. P.O. Box 400, 85 Malmo Ct. Maple, ON L0J 1E0 416-832-2276 *www.ancochemicals.com*	X																	
Armtec 15 Campbell Rd. Guelph, ON N1H 6P2 519-822-0210 *www.big-o.com*	X	X				X					X	X	X					X
Armtec Construction Products 3-191 Caldari Rd. Concord, ON L4K 4A1 905-738-3172 *www.armtec.com*	X	X											X					

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Associated Geotechnical Systems Inc. 50 Steeles Ave. E. Milton, ON L9T 4W9 416-878-7228					X						X	X	X			X		
Atlantic Industries 560 Waydom Ayr, ON N0B 1E0 519-622-8600 *www.ail.ca*		X																
Armtec 1370 Speedvale Ave., Suite #2 Guelph, ON N1H 7M7 519-763-2360 1-800-265-9391	X	X			X	X	X			X	X	X	X			X	X	X
B Double J Construction Ltd. 3286 Aubrey Rd. Mississauga, ON L5L 5C7 905-828-0190	X			X														
Big "O" Drain Tile Co. Ltd. P.O. Box 970 Exeter, ON N0M 1S0 519-235-0870 *www.bigodrain.ca*		X																X
BlueGrass Hydroseeding 13072 Tenth Lane Stouffville, ON L4A 7X4 905-640-9894	X			X										X	X			
Brunton Greg Landscapes 932 Baron Dr. Fort Erie, ON L2A 6G8 905-871-9788	X			X										X	X			
C.I.L. Inc. 90 Sheppard Ave. E. Willowdale, ON M2N 6H2 416-229-7000 *www.cilinc.com*													X					

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Caledon Hydro-Seeding 15354 Mount Wolfe Albion, ON L0N 1P0 905-880-8909 *www.caledonhydroseeding.com*	X			X														
Canada Culvert & Metal Products 150 Centennial Rd. Orangeville, ON L9W 3Z8 1-888-282-9334 *www.fsiculvert.com*		X																X
Canada Culvert & Metal Products 5 Lowry Dr. Brampton, ON L7A 1A3 905-495-9648 *www.fsiculvert.com*		X																
Canfield Wayne Backhoe 36 Main St. Rideout, ON P9N 3E6 807-468-9088		X											X					
Central Ontario Hydroseeding 111 Dunlop St. E. Barrie, ON L4M 1A6 705-722-1628	X			X										X	X			
Coldstream Concrete Ltd. R.R. 2 Ilderton, ON N0M 2A0 519-666-0604 *www.coldstream concrete.com*	X	X		X	X							X	X					X
Concrete Pipe Co. 1555 Matheson Blvd. E. Mississauga, ON L4W 1H9 905-625-5900		X																X

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Corrugated Pipe Company Ltd. 362 Lorne Ave. Stratford, ON N5A 6S4 519-271-5553		X																X
Dean Construction Co Ltd. 2720 Front Rd. LaSalle, ON N9J 2N5 519-734-8999 *www.deanconstructioncompany.com*	X			X			X											
Dominion Textile Inc. 1400 Aberdeen St. Hawksbury, ON K6A 1K7 613-632-2788													X					
Doug Formager Enterprises Ltd. 2295 3rd Ave. W., P.O. Box 483 Owen Sound, ON N4K 5P7 519-376-4364	X																	
Dupont Canada, General Products Division P.O. Box 2200, Streetsville Mississauga, ON L5M 2H3 416-821-5169 *www.ca.dupont.com*													X					
Dynex Excavating Contractors Ltd. 80 Costa Ave. Floor 2 Thornhill, ON L4K 1N2 905-669-5923	X			X														
Eckstein Masonry Supply 80 Bowes St. Parry Sound, ON P2A 2L7 705-746-2179 *www.ecksteinmasonry.com*		X				X												

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Emo Feed Service Ltd. 21 Canning Ln. Emo, ON P0W 1E0 807-482-2017	X	X												X	X			
Farr Drainage Ltd. 395 Niagara St. St. Catharines, ON L2M 4V9 905-641-1234	X			X														
Filtrexx Canada Inc. 324 Governor's E., R.R. 1, Brantford, ON N3L 3E1 519-753-0324 *www.filtrexxinternational.com*	X			X		X												
Form & Build Supply Inc. 1175 Frances St. St. London, ON N5W 2L9 519-453-4300 1-800-265-1075 *www.formandbuild.com*	X				X							X	X			X	X	
Geosynthetic Systems 3543 Conroy Rd. Ottawa, ON K1T 3F6 1-866-490-4436 *www.geosyntheticsystems.ca*	X			X		X		X				X	X	X	X	X		
Graham Turf Seeds Ltd. 1702 Elm Tree Rd.,R.R.1 Lindsay, ON K9V 4R1 1-877-247-1082 705-878-8822 E-MAIL: graham@grahamturf.com															X			
Groom-Callaghan Supply Co Ltd. 379 Agnes St. Sudbury, ON P3B 2J2 705-675-2261 *www.groomcallaghan.ca*		X																

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Hollandia Nursery Sod 3725 Regional Rd. 15 Janesford, ON P0M 1L0 705-897-5146	X			X									X			X		
Home Hardware (various locations) *www.homehardware.ca*															X			
Hotte Marine Contracting Ltd. 2342 Front Rd. LaSalle, ON N9J 2C4 519-734-6323	X			X														
Hubbell E S & Sons Ltd. 1385 Franklin St. North Bay, ON P1A 2X3 705-474-2830	X	X		X									X		X			
Ideal Drain Tile Ltd. P.O. Box 25 Cedar Springs Blenheim, ON N0P 1E0 519-676-2814 *www.idealpipe.ca*		X																X
Ideal Drain Tile Ltd. 1196 W. Sunningdale Rd. London, ON N6G 5B6 519-473-2669 *www.idealpipe.ca*		X																
International Erosion Control Systems 24585 Pioneer Line West Lorne, ON N0L 2P0 519-768-1420 1-800-821-7462 *www.iecs.com*							X											
Jones Bev 2589 Quarry Rd. Waubaushene, ON L0K 2C0 705-538-2704		X																

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Kevin Steele Landscaping Inc. 595 Belleview Blvd. Ridgeway, ON L0S 1N0 905-894-4715	X			X										X	X			
King Hydroseeding & Sodding Ltd. P.O. Box 1211 Kleinburg, ON L0J 1C0 416-213-8318	X			X										X	X			
Lafarge Pipe & Precast 1555 Matheson Blvd. E. Mississauga, ON L4W 1H9 905-625-5900 *www.lafargenorthamerica.com*		X				X												
Layfield Plastics Ltd. 20 Staffen Dr., Unit 9 Vaughan, ON L4K 2Z7 905-761-9123 *www.geomembranes.com*	X					X						X	X	X	X	X		
LGL Limited 3365 Harvester Rd. Burlington, ON L7N 3N2 905-333-1667 *www.lgl.com*	X						X	X										
Maaskant Brothers Agricultural Products R.R. 2 Clinton, ON N0M 1L0 519-524-9081																		X
M & R Feeds & Farm Supply 1185 Pembroke St. E. Pembroke, ON K8A 7R6 613-732-2843 *www.mandrfeeds.com*		X												X	X			
Maccaferri Canada Ltd. 400 Collier MacMillan Dr., Unit B Cambridge, ON N1R 7H7 519-623-9990	X	X		X		X		X				X	X	X	X	X		

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
MacDonald D. L. Construction Ltd. 5741 Highway 138 Cornwall, ON K6K 1R9 613-932-3173		X																
McCarthy Land Improvement 3818 County Rd. 47 Brechin, ON L0K 1B0 705-484-9908	X			X														
North Bay Mattawa Conservation Authority 15 Janey Ave. North Bay, ON P1C 1N1 705-474-5420 *www.nbmca.on.ca*	X			X														
Northern Pipe Supply Ltd. 465 E. Second Line Sault Ste. Marie, ON P6B 4K2 705-254-7182		X																
Northwest Culvert 927 Alloy Dr. Thunder Bay, ON P7B 5Z8 807-623-1721		X																X
O'Hara Trucking & Excavating Inc. 71 Berryman Ave. St. Catharines, ON L2R 0A2 905-684-1447	X			X														
Ontario Seed Company P.O. Box 7 Waterloo, ON N2J 3Z6 519-888-0557															X			
Pederson J K Landscaping Ltd. 2408 Manotick Station Rd. Osgoode, ON K0A 2W0 613-821-2088	X			X														

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Pickseed Canada Inc. P.O. Box 304, 1 Greenfield Rd. Lindsay, ON K9V 4S3 705-878-9240 1-800-661-4769 *www.pickseed.com*															X			
Plantsmen 954173 7th Line, R.R. 5 Orangeville, ON L9W 2Z2 519-942-4129 *www.davidwarburton.yp.ca*	X			X										X	X			
Porter's Septic Tank Service 717767 6 & 10 Hwy., R.R. 4 Owen Sound, ON N4K 5N6 519-372-1636		X																
Potvin-Scott Contractors Ltd. 820 Montreal St. Thunder Bay, ON P7E 6P8 807-475-5699	X			X														
Quality Seeds Ltd 8400 Huntington Road, R.R. 1 Woodbridge, ON L4L 1A5 905-856-7333 1-877-856-SEED Email: ari@qualityseeds.ca															X			
R & M Construction 254 N. Main St. Acton, ON L7J 1W9 519-853-3966	X			X														
Rosslyn Service Ltd. 3404 Rosslyn Rd. Thunder Bay, ON P7C 5M9 807-939-2521		X																
Septech Septic Service 1065 Bonnybrook Dr. Orillia, ON L3V 6H4 705-327-5408	X			X														

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Simcoe Block Limited 261 Cedar Line., P.O. Box 1348 Bracebridge, ON P1L 1V4 705-645-5296 *www.simcoeblock.com*		X				X												
Simcoe Building Center 140 Ferndale Dr. Barrie, ON L4M 4T2 705-728-1773 *www.simcoeblock.com*		X																
Skene Transfer & Supply 19200 Hwy. 17 W. Oxdrift, ON P0V 2J0 807-937-5960		X																
Speare Seeds P.O. Box 171 Harriston, ON N0G 1Z0 519-338-3840 Email: relliott@speareseeds.ca															X			
Soren Construction Ltd. 3304 Mainsail Cres. Mississauga, ON L5L 1H2 905-820-8243	X			X														
Stayner TIM-BR Mart 1014 Centre Line Rd. Stayner, ON L0M 1S0 705-428-2420		X																
Terrafix Geosynthetics Inc. 180 Bethridge Road Etobicoke, ON M9W 1N3 416-674-0363 *www.terrafixgeo.com*	X				X						X	X	X			X	X	
Traders Metal Co Ltd. 131 Yates Ave. Sault Ste. Marie, ON P6A 5M1 705-759-1090		X																
TSC Stores (various locations) *www.tscstores.com*															X			

SUPPLIER	Erosion Control Blankets	Culverts	Cofferdams	Gabions	Grid Systems	Revetments	Shoreline/Coastal Protection	Soil Bioengineering	Swale and Riprap Materials	Temporary Stream Damming Equipment	Cellular Confinement Systems	Geogrids	Geomembranes and Geotextiles	Hydroseeding	Seeds, Seed Mixes	Silt Fence	Coir Wattles	Specialized Drainage Products
Twin-City Interloc 11 Chestview Pl., Unit 2 Kitchener, ON N2B 3X6 519-745-8854 *www.twincityinterloc.com*	X			X		X								X	X			
Underground Specialties Inc. 25 Borrowman St. Chatham, ON N7M 5J5 519-354-9243 *www.undegroundspecialties.ca*		X																
United Extrusions Ltd. 33 Centennial Rd. Orangeville, ON L9W 1R1 519-941-5175		X																
United Rentals (various locations) 1-800-877-3687 *www.unitedrentals.com*	X		X							X		X	X			X	X	
Verdyol Plant Research Ltd. 5009 Conc. 13, R.R. 4 Cookstown, ON L0L 1L0 705-458-9601 *www.verdyol.ca*	X												X					
Wilco Landscape Contractors Ltd. 1970 Broadway Ave. Thunder Bay, ON P7C 5N5 807-475-5951 *www.wilco.ca*	X			X										X	X			
Wilkinson Erosion Control Ltd. 79 Haldimand Rd. 55 Nanticoke, ON N0A 1L0 519-587-5544	X			X														
Winona Concrete & Pipe Products Ltd. 489 W. Main St. Grimsby, ON L3M 1T4 905-945-8515 *www.winonaconcrete.com*		X																

Appendix E. Innovative Approaches

Appendix E

Innovative Approaches to Solving Soil Erosion Problems on Steep Slopes and Along Watercourses

Wherever possible in solving erosion concerns, consider an approach that addresses the immediate soil erosion issue, and also provides a broader ecological benefit. This may involve simple add-ons, and in some instances may mean an entirely new or different approach to solving the problem.

These solutions generally include natural protective systems or soil bioengineering. Soil bioengineering is the use of living vegetation, logs, timber and boulders to prevent erosion and control sediment, with the added benefit of providing wildlife habitat. Live woody shrubs and grasses are the functioning components of the system that grow with the system and get stronger over time. Using natural protective systems will not fit all agricultural drainage applications.

Consider using vegetation to control erosion along an agricultural drain where it's acceptable to the landowner, drainage system designer, municipality, and:

- flow is year round
- the slope of the watercourse is less than 0.005 m/m (0.005 ft/ft) of drain
- some floodplain functioning is available

There are also innovative erosion control systems that rely on rock riprap or have limited use of living vegetation that may be more suitable in agricultural drainage systems.

Vegetated-based Solutions

Live staking, fascines and mattressing are solutions that rely solely on vegetation to control erosion. These techniques work very well, but their use should follow the limitations listed above.

Live Staking – Shrub willow cuttings less than 75 mm (3 in.) in diameter and 1 m (3 ft) long are pushed/pounded into the ground at 600 mm (2 ft) spacing.

Fascine – Bundles of shrubs, 2-6 m (6.6-20 ft) long and 150-200 mm (6-8 in.) in diameter, are tied together and installed in a trench across the slope. The material is covered with topsoil, leaving the ends slightly exposed, and bundles are secured with live and dead stakes.

Mattressing – Shrub material 15-50 mm (5/8-2 in.) in diameter and up to 2 m (6.6 ft) long are laid in a trench with the tops facing upwards at a 250 mm (10 in.) thickness. The mattress is staked at 1 m (3 ft) intervals with dead and live stakes. A grid of live material or twine is secured to the stakes, which are then tamped into the ground to compress the mattress. Soil is then placed on the material, leaving about 30% of the shrubs exposed.

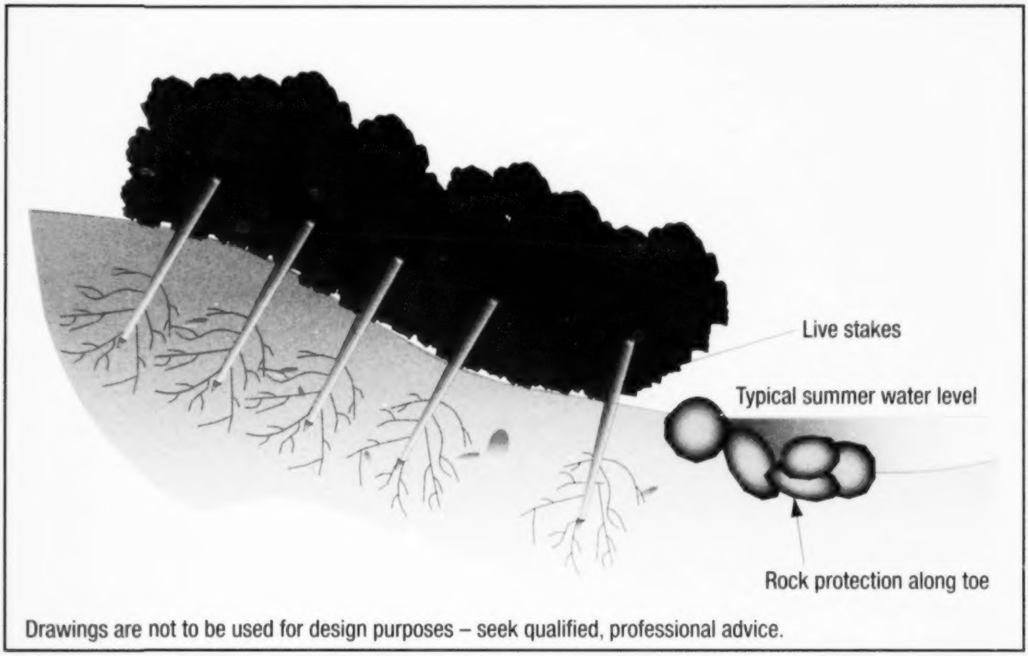


Figure E.1. Live Staking

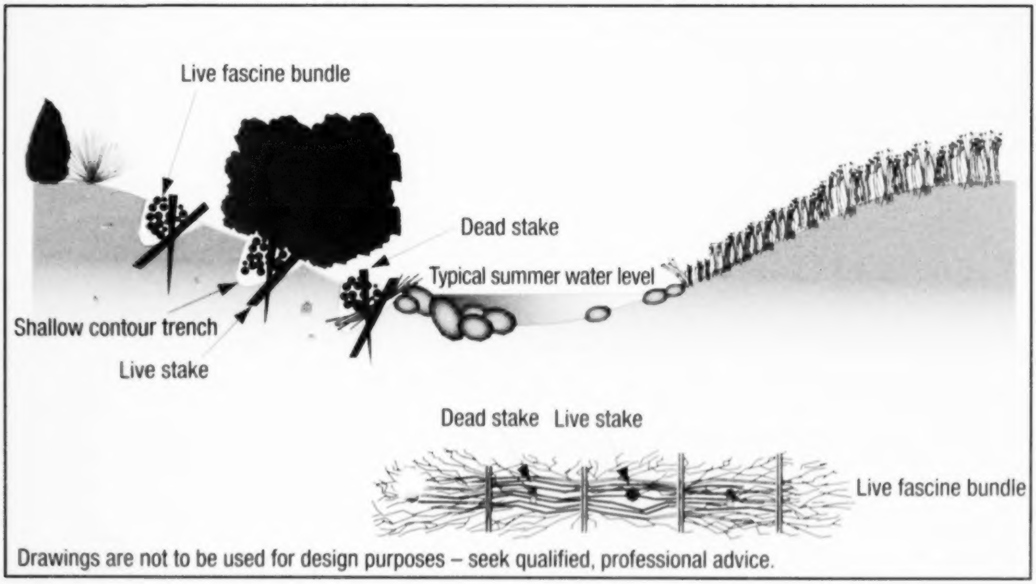


Figure E.2. Live Fascines

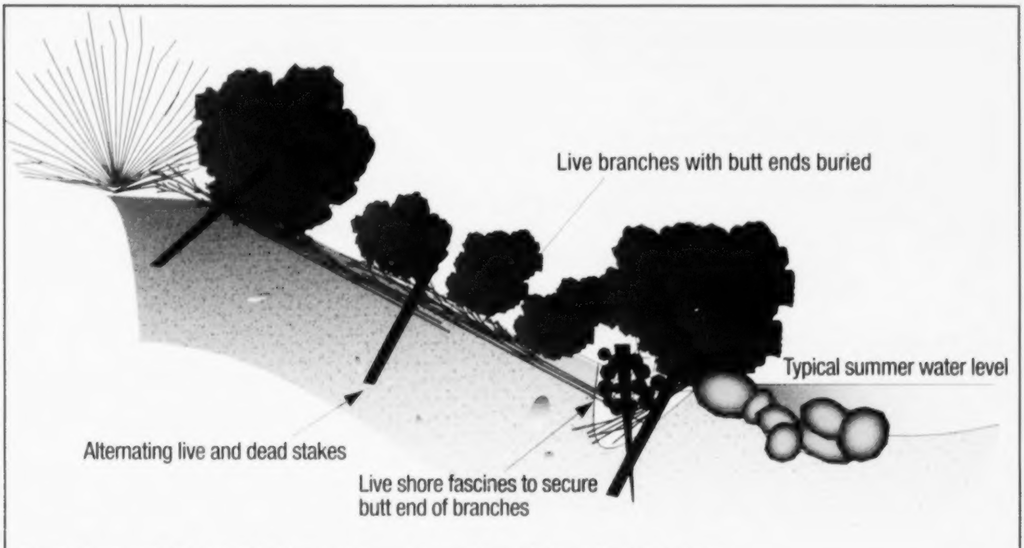


Figure E.3. Brush Mattress

Rock, Timber and Vegetation-based Solutions

There are a number of solutions that provide immediate erosion protection by using rock and timber in the design and construction. Although vegetation is incorporated into the solution, it is not located to impact flow at the water's edge, but rather above the flow.

Cribwall – Cribwalls may be suitable in areas with limited land space that require near vertical streambanks. Cribwalls are made of a box-like arrangement of interlocking, untreated lumber fastened together and filled with live shrub vegetation and good quality earth fill. Place rock riprap along the toe of the structure.

Coir Logs – These 300 mm (12 in.) diameter prefabricated rolls of coconut fibre, bound together with twine, may be secured with 50 mm x 50 mm (2 in. x 2 in.) non-treated stakes along the toe of a watercourse. Alone, they will create a new stream edge and may be enhanced by planting woody or herbaceous vegetation directly into the log.

Root Wads – Using large boulders (1 m (3 ft) diameter), wooden poles (150-250 mm (6-10 in.) diameter) and tree trunks with the roots attached is a natural method to rebuild eroded streambanks and control erosion in the future.

Rock Riprap Plus Bioengineering – Incorporate bioengineering techniques like live staking and fascines where stream grades are excessive and vegetation alone can't protect a bank from erosion.

Environmentally-Friendly Gabion Baskets – Use gabions for erosion control where stream grades are excessive and vegetation alone can't protect a bank from erosion, and there's no space to slope the streambanks. These rock-encased wire baskets are usually enhanced using live vegetation. Place live stakes directly through the basket, or use other bioengineering methods, such as fascines, along the gabion basket toe and lower bank for protection.

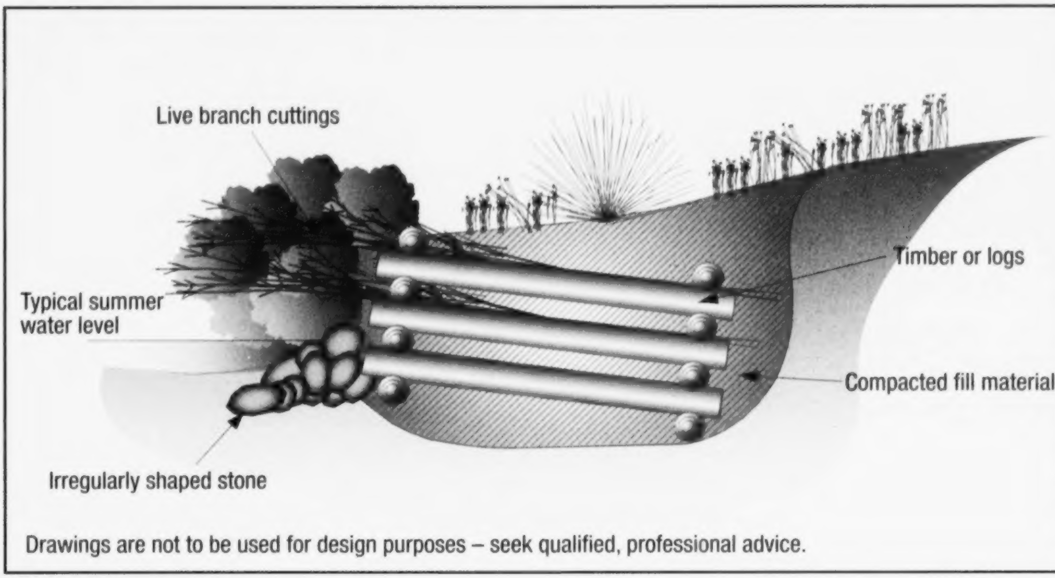


Figure E.4. Cribwall

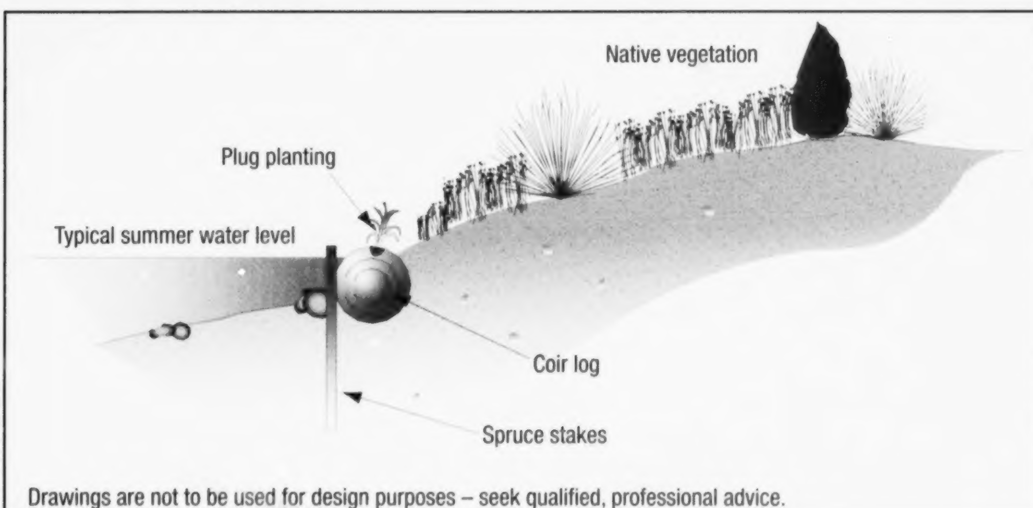
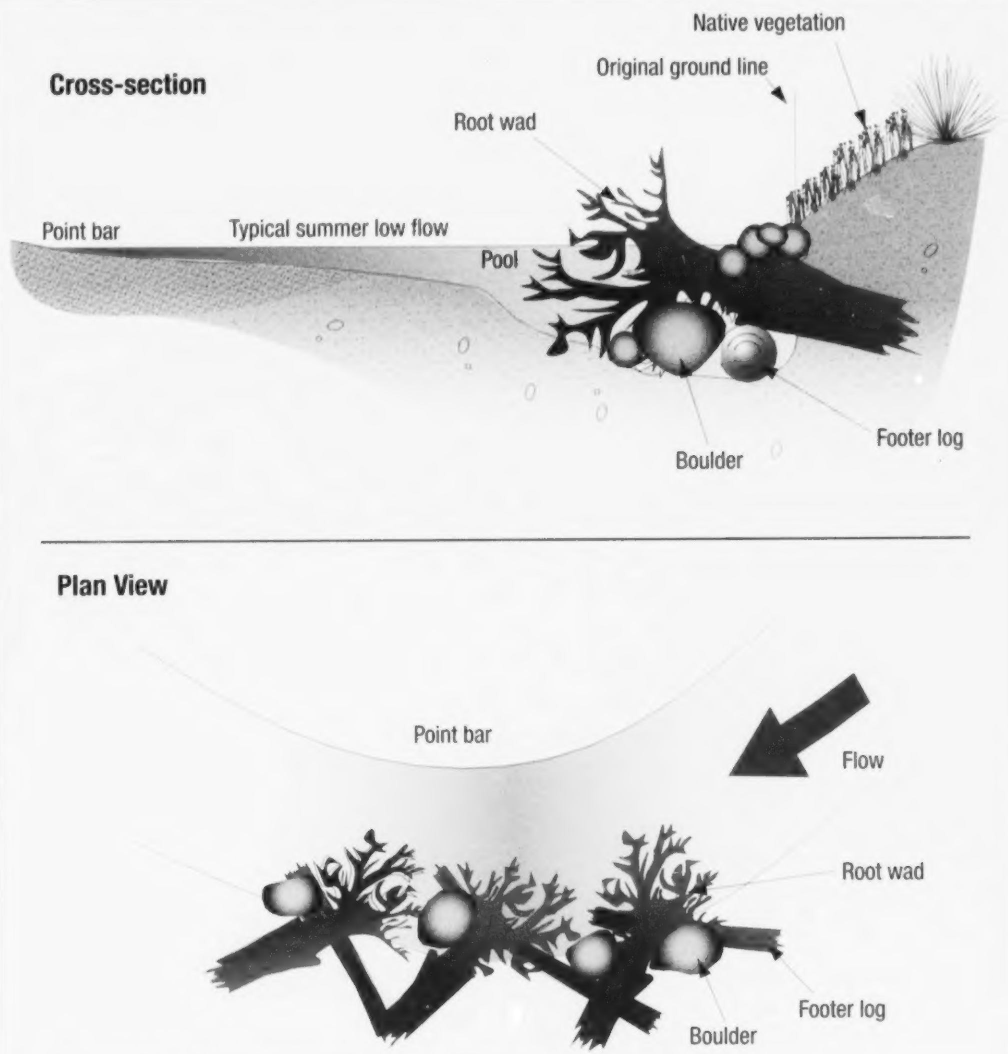


Figure E.5. Coir Logs



Drawings are not to be used for design purposes – seek qualified, professional advice.

Figure E.6. Root Wad Bank Revetment

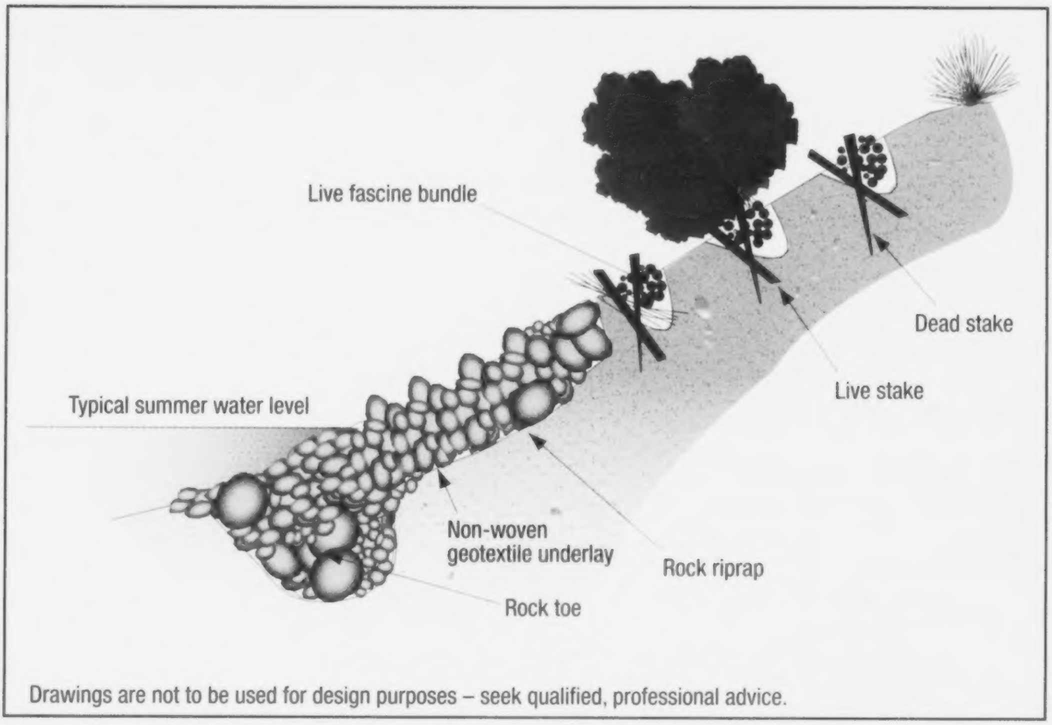


Figure E.7. Bank Protection with Rock Riprap and Bioengineering

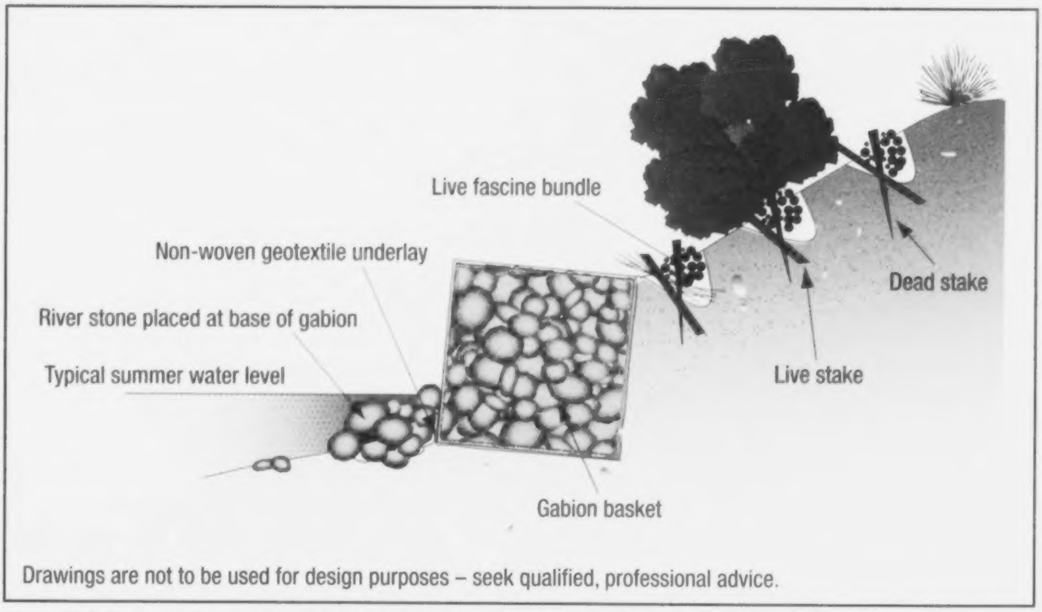
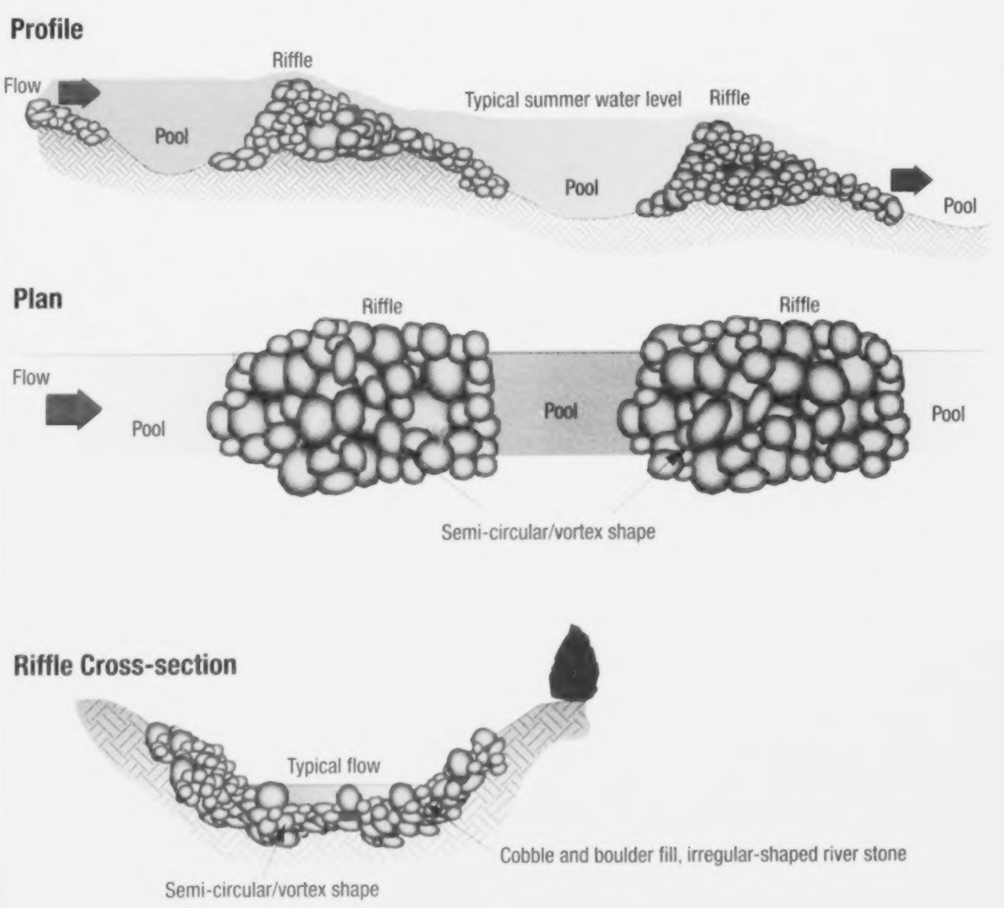


Figure E.8. Bank Protection with Gabion Baskets and Bioengineering

Rock and Timber-based Solutions

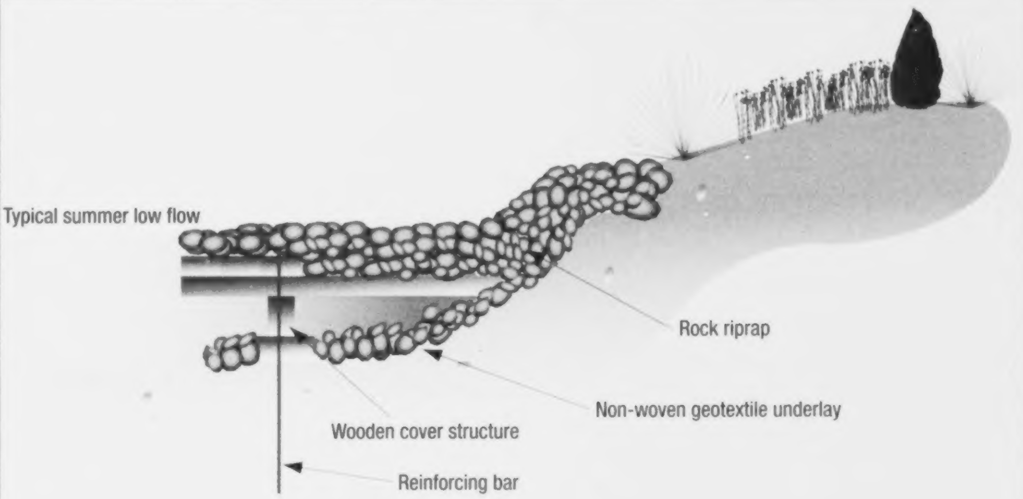
Rock Riffles – Most bank instability and erosion problems in a watercourse are attributed to the tendency of the watercourse to create a natural channel pattern that utilizes a minimum amount of energy. Some drainage engineers consider the natural flow dynamics in the design of open drains or ditches. The result may be a traditional channel with a series of pools and riffles at designed intervals. This layout assists the watercourse in dissipating energy and reduces stress on the banks. In addition, the rock areas provide improved habitat for aquatic life.

Wooden Cover Structures – Use hardwood lumber along most watercourses to construct overhanging banks that provide shelter for fish during low flow periods. Place rock riprap above the structure to secure it and protect the bank from scour.



Drawings are not to be used for design purposes – seek qualified, professional advice.

Figure E.9. Rock Riffles



Drawings are not to be used for design purposes – seek qualified, professional advice.

Figure E.10. Wooden Cover Bank Protection with Rock Riprap Support

Bioengineering References

Environment Canada, Ontario Region. Environment Canada – Great Lakes 2000 Cleanup Fund. Tel.: (905) 336-6281, *http://sustainabilityfund.gc.ca/default.asp?lang=En&n=321CF8C5-1*

Gray, Donald H. Biotechnical Slope Protection and Erosion Control. Krieger Publishing Company, Malabar, FL.

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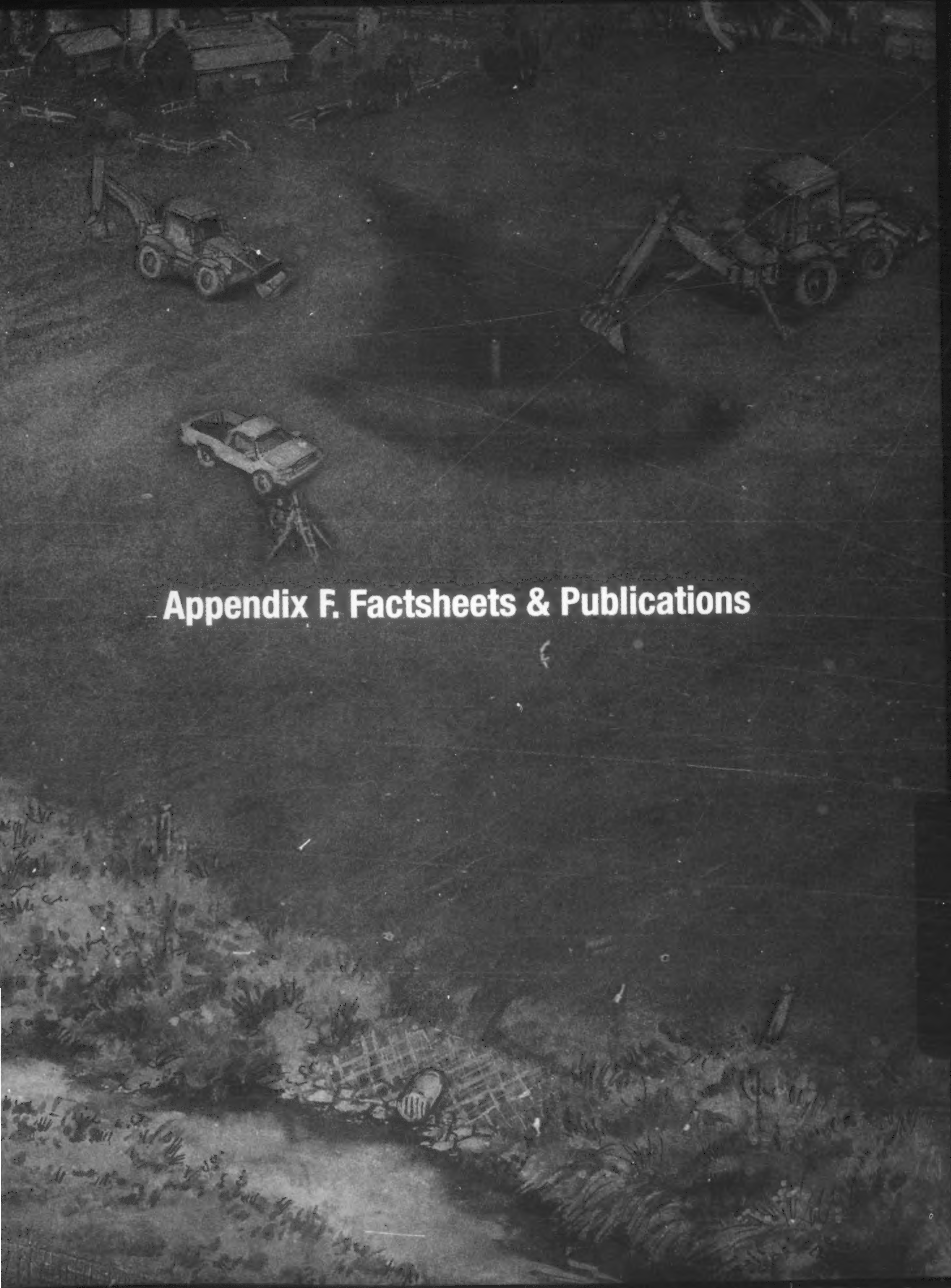
Schiechtl, H.M. *Water Bioengineering Techniques for Watercourse Bank and Shoreline Protection.* Copp Clark Professional 1-800-815-9417.

United States Department of Agriculture, Forestry Services. Soil Bioengineering – *An Alternative for Roadside Management.* *www.wsdot.wa.gov/eesc/design/roadside/SB/pdf/Soil%20bioeng.pdf*

United States Department of Agriculture, Natural Resources Conservation Services, Engineering Field Handbook. Soil Bioengineering for Upland Slope Protection and Erosion Reduction. Chapter 18.NTIS Access No. PB95-181269. New NRCS Directives No. 210-VI-NEH 650.18. *www.info.usda.gov/CED/ftp/CED/EFH-Ch18.pdf*

Upper Thames River Conservation Authority. *www.thamesriver.on.ca*

Appendix F. Factsheets & Publications



Appendix F

OMAFRA Factsheets and Publications

Factsheets

Control of Soil Erosion, Order No. 95-089

Drainage Benefits, Order No. 85-118

Drain Problems, Order No. 84-017

Drop Inlet Spillways, Order No. 85-057

Fencing of Watercourses to Control Erosion, Order No. 00-049

Gabion Basket Drop Structures along Waterways, Order No. 99-049

Grassed Waterways, Order No. 94-039

Gully Erosion Control, Order No. 88-059

Maintenance of the Drainage System, Order No. 87-062

Management of Drained Fields, Order No. 90-156

Programs and Services for Ontario Farmers, Order No. 05-073

Seeding of Erosion Control Projects, Order No. 90-231

Soil Erosion – Causes and Effects, Order No. 87-040

Strip Cropping for Water Erosion Control, Order No. 87-171

Surface Drainage, Order No. 82-082

The Planning and Maintenance of an Erosion Control System, Order No. 97-015

Tile Drainage Outlets, Order No. 90-233

Universal Soil Loss Equation (USLE), Order No. 00-001

Use of Rock in Erosion Control Projects, Order No. 90-227

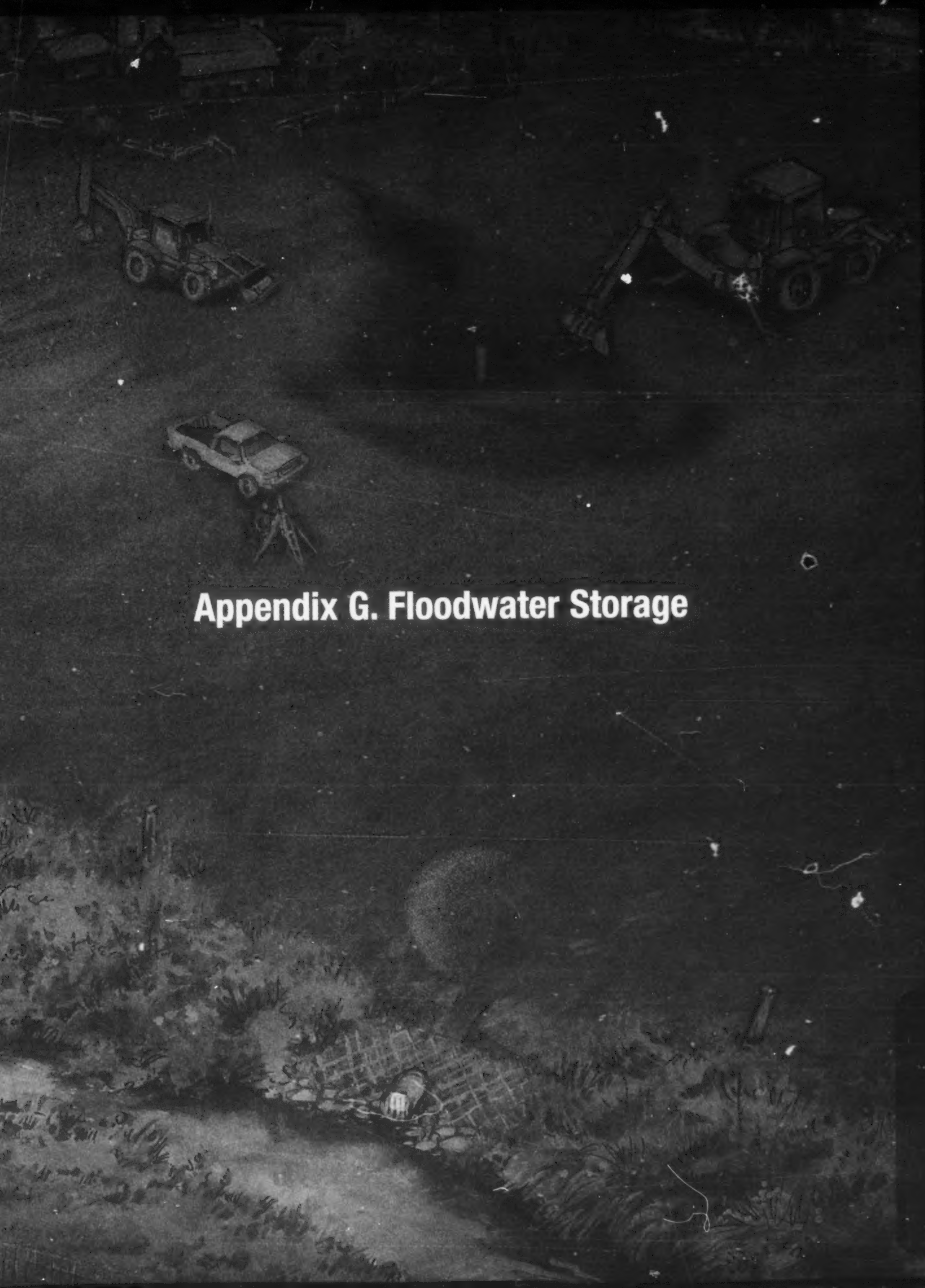
Use of Earthen Berms for Erosion Control, Order No. 99-047

Water and Sediment Control Basins, Order No. 89-167

Publications

Publication 29, *Drainage Guide for Ontario*

Appendix G. Floodwater Storage



Appendix G

Floodwater Storage

Available, natural ponding areas can be used to significantly reduce the size of outlet structures. Water may also be held back by forming a dam or berm and using it to temporarily store a volume of water (12-24 hours).

Ponding of water serves as a buffer to the flowing water. After a storm begins, water gradually starts to move toward an outlet from the collection watershed. As the rainfall continues, the flow of water gradually intensifies. When the rainfall finally ends, the intensity of the flow at the outlet gradually lessens. The Soil Conservation Service method for determination of runoff from a watershed area yields an outlet flow vs. time graph as shown in Figure G.1. Each watershed has its own characteristic flows following a storm.

Influencing factors include the following:

- watershed slope or gradient
- watershed length
- general shape of the watershed
- type of vegetative cover
- soil type
- moisture content of the soil
- cropping and erosion control practices

All these factors determine how quickly water reaches an outlet from the watershed following a storm. More information on all these factors is in Section 2.3.

If an outlet structure has no means of making use of ponding, ensure the structure is large enough to handle the peak flow generated within the watershed. The capacity of the outlet structure must be large and consequently the loads on downstream structures will be temporarily very high. A pond allows this peak flow to be reduced by accumulating flows and releasing them over a longer period of time. Figure G.2 indicates the effect of floodwater storage on the outlet flow rate vs. time characteristics.

Complete an economic analysis of installing a floodwater storage before proceeding. Making use of floodwater storage almost always improves the characteristics of a watershed. High value crops that are intolerant of standing water are the exception (e.g. tomatoes). Most field crops (corn, soybeans, etc.) can tolerate standing water for 12-24 hours (or as recommended by a crop technology specialist) without damage.

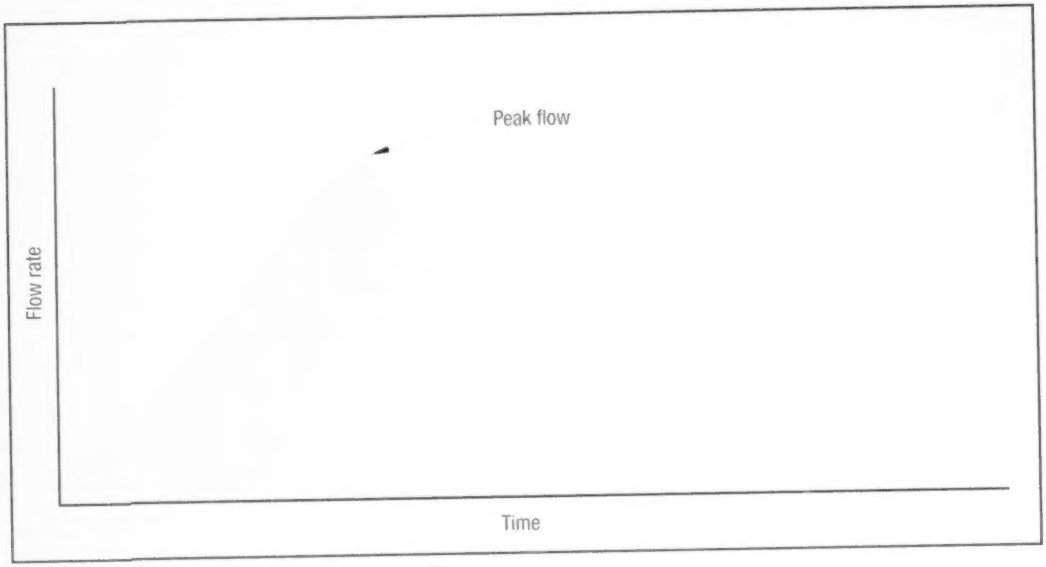


Figure G.1. Watershed Flow Rate vs. Time

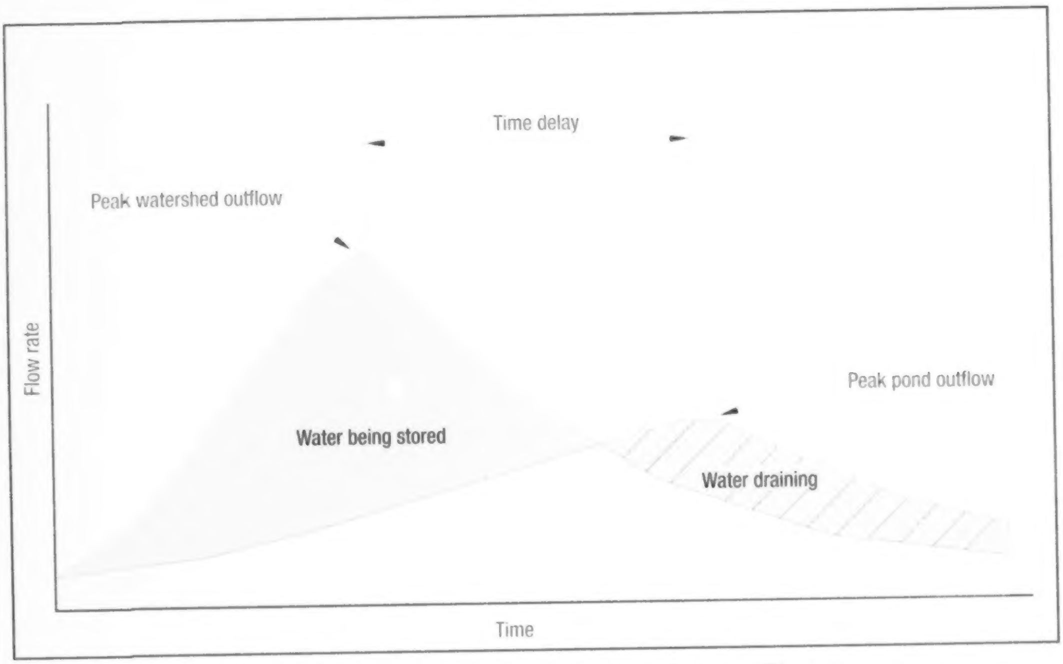


Figure G.2. Watershed Flow Rate vs. Time and Pond Flow Rate vs. Time

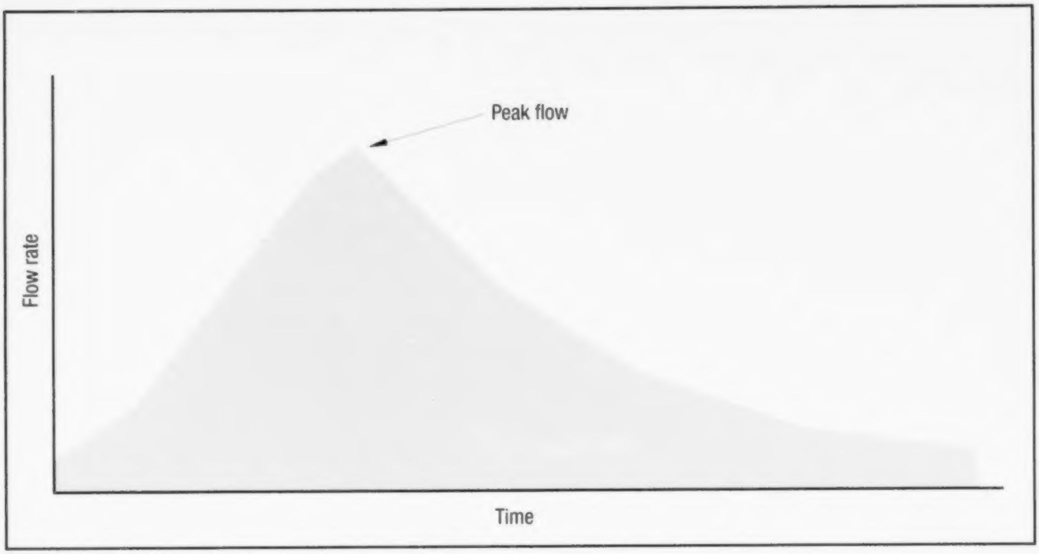


Figure G.1. Watershed Flow Rate vs. Time

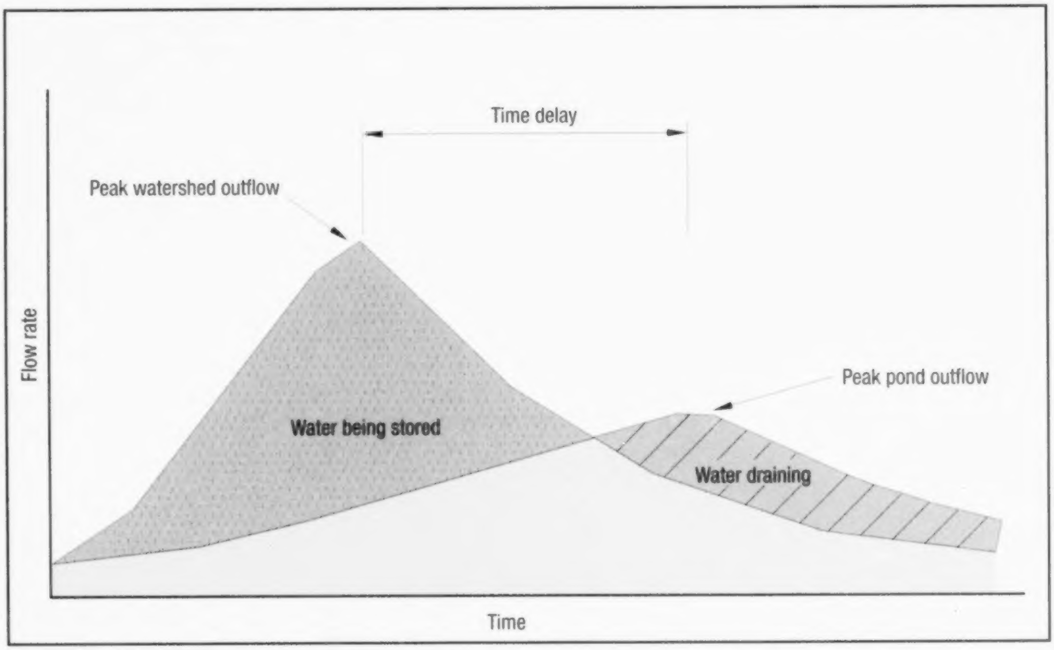


Figure G.2. Watershed Flow Rate vs. Time and Pond Flow Rate vs. Time

Floodwater Storage Design Information Sheet

Use this form to calculate the quantity of water exiting from a pond. It will indicate the effectiveness of a particular size of pond in reducing the peak flow associated with an upstream watershed. Follow all of the instructions on this form and on all of the associated figures.

1. Watershed area	____ ha	____ ac
2. Average grade of watershed		____ %
3. Runoff curve number from Tables 2.2 – 2.4		____
4. Peak flow from watershed for a 25 year storm from Tables 2.5-M to 2.11-M (2.5-I to 2.11-I)	____ m^3/s	____ ft^3/s
5. Obtain one-day rainfall for the watershed location from Table G.1	____ mm	____ in.
6. Obtain the depth of runoff (Vr) from Table G.2-M (G.2-I)	____ mm	____ in.
7. Calculate the ponding volume available	____ m^3	____ ft^3
8. Calculate the equivalent depth of storage over the entire watershed $Vs = \frac{\text{pond volume x 1,000}}{\text{hectares x 10,000}} =$ ____ mm $Vs = \frac{\text{pond volume x 12}}{\text{acres x 43,560}} = \frac{\text{\_\_\_\_ x 12}}{\text{\_\_\_\_ x 43,560}} =$ ____ in	____ mm	____ in.
9. Refer to Figure G.3 to decide which chart to use Table G.3 or Table G.4-M (G.4-I) **Choose one** Table G.3 or Table G.4-M (G.4-I)		

If Table G.3 is used, divide Vs by Vr (i.e. divide answer in Step 8 above by the answer in Step 6)

$\frac{Vs}{Vr} =$ ____ = ____

Using Table G.3, read the first decimal place of Vs/Vr on the left side and the second decimal place across the top. Obtain the answer where the two lines intersect:

Answer: ____

Multiply this answer by the peak flow in step 4 (above) to obtain the peak pond outflow.

____ x ____ = ____ m^3/s (ft^3/s)

If Table G.4-M (G.4-I) is used, read Vs along the top of the chart and Vr along the left side to obtain discharge:

Answer: ____ $m^3/s/ha$ ($ft^3/s/ac$)

Multiply the answer (above) by the number of hectares (acres) in the watershed to obtain the peak pond outflow.

____ x ____ = ____ m^3/s (ft^3/s)

Table G.1. One-day Rainfall for Selected Cities and Towns in Ontario

65 mm (2.5 in.)	76 mm (3 in.)	90 mm (3.5 in.)	102 mm (4 in.)	115 mm (4.5 in.)	127 mm (5 in.)	140 mm (5.5 in.)	152 mm (6 in.)
Ansonville	Ajax	Ailsa Craig	Armstrong	Alliston	Barrie	Beaverton	Brampton
Bancroft	Alexandria	Atikokan	Aurora	Barrefield	Cannington	Missisauga	
Cochrane	Almonte	Belmont	Brantford	Bracebridge	Coboconk	Port Credit	
Cornwall	Arnprior	Brockville	Burks Falls	Bradford	Elmvale	Streetsville	
Gore Bay	Belleville	Campbellford	Burlington	Camp Borden	Georgetown		
Hearst	Bowmanville	Centralia	Caledonia	Gravenhurst	Guthire		
Kapuskasing	Brighton	Chapleau	Cambridge	Grimsby	Honey Harbour		
Lansdowne House	Brooklin	Clinton	Chatham	Guelph	Midland		
Moosonee	Carleton Place	Corruna	Collingwood	Kingston	Milton		
Sault Ste. Marie	Cavan	Deep River	Dryden	Martin	Orillia		
Smooth Rock Falls	Chelmsford	Deseronto	Dunbarton	Muskoka Airp.	Penetanguishene		
	Chesley	Dorchester	Dunnville	Oakville	Toronto		
	Cobourg	Dutton	Englehart	Sioux Lookout			
	Colborne	Earlton	Fonthill	Smithville			
	Dorion	Edison	Fort Erie	Stratford			
	Dresden	Embro	Graham	Vittoria			
	Durham	Espanola	Hagersville				
	Geraldton	Exeter	Hamilton				
	Hanover	Fergus	Huntsville				
	Hornepayne	Forest	Jarvis				
	Jellicoe	Fort Francis	Kinmount				
	Kemptville	Gananoque	Kitchener				
	Killaloe Sta.	Glencoe	Lindsay				
	Kincardine	Goderich	Minden				
	Lions Head	Haileybury	Newmarket				
	Listowel	Haliburton	North Bay				
	Maitland	Hastings	Port Burwell				
	Markdale	Hawkesbury	Port Colborne				
	Matheson	Ingersoll	Port Dover				
	Milverton	Kenora	Port Stanley				
	Mitchell	Kirkland Lake	Red Lake				
	Morrisburg	Lakefield	Ridgeway				
	Mount Forest	Leamington	Simcoe				
	Nakina	London	Sundridge				
	Newcastle	Lucan	Tillsonburg				
	Orangeville	Mattawa	Uxbridge				
	Oshawa	Napanee	Waterloo				
	Owen Sound	New Liskeard	Welland				
	Pagwa River	Niagara Falls	West Lorne				
	Perth	Norwood					
	Petrolia	Ottawa					
	Picton	Paris					
	Porcupine	Parkhill					
	Port Elgin	Parry Sound					
	Port Hope	Pembroke					
	Prescott	Petawawa					
	Raith	Peterborough					
	Renfrew	Plattsville					
	Schreiber	Pt. Alexander					
	Smiths Falls	Port Perry					
	Southampton	Princeton					
	South Porcupine	Rockland					
	Stirling	St. Catharines					
	Strathroy	St. Marys					
	Sudbury	St. Thomas					
	Thunder Bay	Sarnia					
	Trenton	Seaforth					
	Wallaceburg	South River					
	Watford	Sturgeon Falls					
	Wawa	Tavistock					
	Whitby	Thamesford					
	Wiarton	Thedeford					
	Windsor	Timagami					
	Wyoming	Trout Creek					
		Trout Lake					
		Vanier					
		Walkerton					
		White River					
		Wingham					
		Woodstock					

Table G.2-M. Runoff Depth (mm), Value Designated Vr

Choose the one-day rainfall value on the left side.
Find the appropriate runoff curve number across the top.
The runoff depth (mm) is found at the intersection of those two lines.

One-day Rainfall (mm)	Runoff Curve Number						
	60	65	70	75	80	85	90
25	0	0	0	0.76	2.03	4.32	8.13
30	0	0	0.76	1.78	3.81	7.11	11.68
36	0	0.51	1.52	3.30	6.10	9.91	15.49
41	0.25	1.27	2.79	5.08	8.64	13.21	19.3
46	0.76	2.29	4.32	7.37	11.18	16.51	23.62
51	1.52	3.56	6.10	9.65	14.22	20.32	27.69
64	4.32	7.62	11.68	16.51	22.61	29.97	38.86
76	8.38	12.95	18.29	24.38	28.04	40.38	50.29
102	19.3	19.88	26.44	42.42	51.82	62.48	74.17
127	33.02	41.01	51.82	62.23	73.41	85.60	98.55

Table G.2-I. Runoff Depth (in.), Value Designated Vr

Choose the one-day rainfall value on the left side.
Find the appropriate runoff curve number across the top.
The runoff depth (in.) is found at the intersection of those two lines.

One-day Rainfall (in.)	Runoff Curve Number						
	60	65	70	75	80	85	90
1.0	0	0	0	0.03	0.08	0.17	0.32
1.2	0	0	0.03	0.07	0.15	0.28	0.46
1.4	0	0.02	0.06	0.13	0.24	0.39	0.61
1.6	0.01	0.05	0.11	0.20	0.34	0.52	0.76
1.8	0.03	0.09	0.17	0.29	0.44	0.65	0.93
2.0	0.06	0.14	0.24	0.38	0.56	0.80	1.09
2.5	0.17	0.30	0.46	0.65	0.89	1.18	1.53
3.0	0.33	0.51	0.72	0.96	1.15	1.59	1.98
4.0	0.76	1.03	1.33	1.67	2.04	2.46	2.92
5.0	1.30	1.65	2.04	2.45	2.89	3.37	3.88

Table G.3. Values of Pond Outflow to Pond Inflow (Qo/Qi) (m^3/s/ha or ft^3/s/ac)

Divide: $\dfrac{\text{watershed storage (Vs)}}{\text{watershed runoff (Vr)}}$

Vs/Vr		Read Second Decimal Place Here									
		0.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
Read First Decimal Place on This Side	0.0	1.00	.99	.98	.96	.95	.94	.92	.91	.90	.88
	0.1	.87	.85	.84	.82	.81	.79	.78	.76	.75	.74
	0.2	.70	.67	.64	.61	.58	.56	.54	.52	.50	.48
	0.3	.47	.45	.44	.42	.41	.40	.39	.38	.37	.36
	0.4	.35	.32	.30	.28	.26	.24	.23	.21	.20	.19
	0.5	.18	.17	.16	.15	.14	.13	.12	.12	.11	.11
	0.6	.10	.10	.09	.09	.08	.08	.07	.07	.07	.07
	0.7	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04
	0.8	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03

Table G.4-M. Discharge Values for Pond Outflow Structures (m^3/s/ha)

Vr – Runoff in Watershed (mm)	Vs – Storage in Watershed (mm)														
	2.5	5	8	10	13	15	18	20	23	25	30	36	41	46	51
25.4	.062	.027	.013	.007	.004										
30.5		.043	.023	.014	.008	.006	.004	.003							
35.6			.040	.022	.015	.010	.006	.005	.004						
40.6				.040	.023	.016	.011	.008	.006	.004					
45.7					.041	.026	.018	.013	.009	.006	.004				
50.8						.045	.029	.019	.015	.010	.006	.004			
55.9							.043	.032	.022	.016	.009	.006	.004		
61.0								.045	.034	.024	.014	.008	.006	.004	
66.0										.034	.020	.012	.008	.006	.004
71.1										.048	.029	.018	.011	.008	.006
76.2											.039	.024	.015	.011	.008
81.3												.034	.022	.014	.010
86.4												.046	.031	.020	.013
91.4													.039	.027	.018
96.5														.034	.024
101.6														.045	.032

Note: Discharge values to the left of the jagged line are to be used for interpolation only. Interpolated values should be less than 0.033 m^3/s/ha.

Table G.4-I. Discharge Values for Pond Outflow Structures ($ft^3/s/ac$)

Vr – Runoff in Watershed (in.)	Vs – Storage in Watershed (in.)														
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0
1.0	.89	.39	.19	.10	.06										
1.2		.62	.33	.20	.12	.08	.05	.04							
1.4			.57	.31	.21	.14	.09	.07	.05						
1.6				.57	.33	.23	.16	.11	.08	.06					
1.8					.59	.37	.25	.19	.13	.09	.06				
2.0						.64	.42	.27	.21	.14	.09	.06			
2.2							.62	.45	.32	.23	.13	.08	.05		
2.4								.65	.49	.34	.20	.12	.08	.05	
2.6										.49	.28	.17	.11	.08	.05
2.8										.69	.41	.25	.16	.11	.08
3.0											.55	.34	.22	.15	.11
3.2												.49	.31	.20	.14
3.4												.66	.44	.28	.19
3.6													.56	.39	.26
3.8														.49	.34
4.0														.65	.45

Note: Discharge values to the left of the jagged line are to be used for interpolation only. Interpolated values should be less than 0.47 $ft^3/s/ac$.

To use this chart, you must first know the value of watershed storage depth (Vs) and watershed runoff depth (Vr). Enter the chart with the appropriate values. If the intersection of the two points lies above the line, the solution can be found in Table G.4-M (G.4-I). If they intersect below the line, use Table G.3.

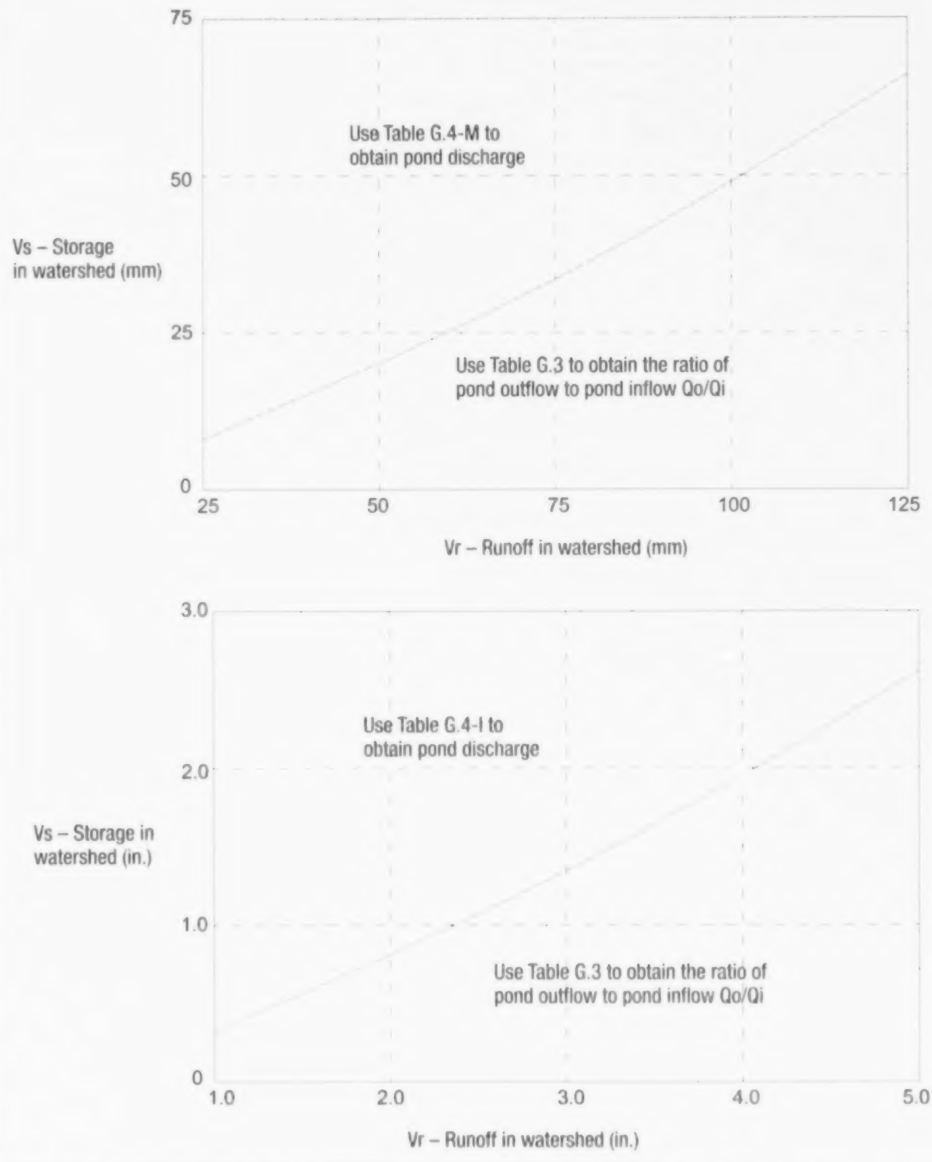


Figure G.3. Choosing the Appropriate Solution Based on the Ratio of Water Storage Volume to Watershed Area

Floodwater Storage – Example Problem #1

Location: Belleville, Ontario
Watershed size = 120 ha (300 ac)
Average grade over the length of the watershed = 2%
Soil type = sandy loam
Cropping practices = row crop/straight row
Hydrologic condition = poor
A pond with a storage capacity of 17,000 m^3 (600,000 ft^3) can be developed at the lower end of the watershed.
Calculate the pond outflow.

Floodwater Storage Design Information Sheet – Example Problem #1

1. Watershed area	120 ha	300 ac
2. Average grade of watershed		2%
3. Runoff curve number from Tables 2.2 – 2.4		81
4. Peak flow from watershed for a 25 year storm from Tables 2.5-M to 2.11-M (2.5-I to 2.11-I)	4.1 m^3/s	145 ft^3/s
5. Obtain one-day rainfall for the watershed location from Table G.1	76 mm	3.0 in.
6. Obtain the depth of runoff (Vr) from Table G.2-M (G.2-I)	32 mm	1.25 in.
7. Calculate the ponding volume available	17,000 m^3	600,000 ft^3
8. Calculate the equivalent depth of storage over the entire watershed $Vs = \frac{\text{pond volume x 1,000}}{\text{hectares x 10,000}} = \frac{17{,}000 \times 1{,}000}{120 \times 100{,}000} = \underline{14}$ mm $Vs = \frac{\text{pond volume x 12}}{\text{acres x 43,560}} = \frac{600{,}000 \times 12}{300 \times 43{,}560} = \underline{0.55}$ in.	14 mm	0.55 in.
9. Refer to Figure G.3 to decide which chart to use Table G.3 or Table G.4-M (G.4-I) **Choose one** Table G.3 or Table G.4-M (G.4-I)		

If Table G.3 is used, divide Vs by Vr (i.e. divide answer in Step 8 above by the answer in Step 6)

$\frac{Vs}{Vr}$ = ______ = ______

Using Table G.3, read the first decimal place of Vs/Vr on the left side and the second decimal place across the top. Obtain the answer where the two lines intersect:

Answer: ______

Multiply this answer by the peak flow in step 4 (above) to obtain the peak pond outflow.

______ x ______ = ______ m^3/s (ft^3/s)

If Table G.4-M (G.4-I) is used, read Vs along the top of the chart and Vr along the left side to obtain discharge:

Answer: <u>0.008</u> $m^3/s/ha$ (<u>0.12</u> $ft^3/s/ac$)

Multiply the answer (above) by the number of hectares (acres) in the watershed to obtain the peak pond outflow.

<u>0.008</u> x <u>120</u> = <u>0.96</u> m^3/s (<u>36</u> ft^3/s)

Floodwater Storage Design Information Sheet – Example Problem #2

Example problem #2 contains all of the same characteristics as Example problem #1, except the pond that can be developed is only 2,830 m^3 (100,000 ft^3). Calculate the pond outflow.

1. Watershed area	120 ha	300 ac
2. Average grade of watershed		2 %
3. Runoff curve number from Tables 2.2 – 2.4		81
4. Peak flow from watershed for a 25 year storm from Tables 2.5-M to 2.11-M (2.5-I to 2.11-I)	4.1 m^3/s	145 ft^3/s
5. Obtain one-day rainfall for the watershed location from Table G.1	76 mm	3.0 in.
6. Obtain the depth of runoff (Vr) from Table G.2-M (G.2-I)	32 mm	1.25 in.
7. Calculate the ponding volume available	2,830 m^3	100,000 ft^3
8. Calculate the equivalent depth of storage over the entire watershed $Vs = \frac{\text{pond volume x 1,000}}{\text{hectares x 10,000}} = \frac{2,830 \times 1,000}{120 \times 10,000} = \underline{2.3}$ mm $Vs = \frac{\text{pond volume x 12}}{\text{acres x 43,560}} = \frac{100,000 \times 12}{300 \times 43,560} = \underline{0.09}$ in.	2.3 mm	0.09 mm
9. Refer to Figure G.3 to decide which chart to use Table G.3 or Table G.4-M (G.4-I) **Choose one** Table G.3 or Table G.4-M (G.4-I)		

If Table G.3 is used, divide Vs by Vr (i.e. divide answer in Step 8 above by the answer in Step 6)

$$\frac{Vs}{Vr} = \frac{2.3 \text{ mm } (0.09 \text{ in.})}{32 \text{ mm } (1.25 \text{ in.})} = \underline{0.07}$$

Using Table G.3, read the first decimal place of Vs/Vr on the left side and the second decimal place across the top. Obtain the answer where the two lines intersect:

Answer: 0.91

Multiply this answer by the peak flow in step 4 (above) to obtain the peak pond outflow.

4.1 x 0.91 = 3.73 m^3/s (132 ft^3/s)

If Table G.4-M (G.4-I) is used, read Vs along the top of the chart and Vr along the left side to obtain discharge:

Answer:______ $m^3/s/ha$ ($ft^3/s/ac$)

Multiply the answer (above) by the number of hectares (acres) in the watershed to obtain the peak pond outflow.

______ x ______ = ______ m^3/s (ft^3/s)

Discussion of Example Problems

In Example Problem #1, the pond is large enough to have a very significant effect on the peak flow generated within the watershed. The peak flow entering the pond is roughly 4.1 m^3/s (145 ft^3/s). The peak flow exiting the pond is roughly 0.96 m^3/s (36 ft^3/s). Therefore, the outlet structure on the pond needs to be designed for only 25% of the incoming flow, representing a significant cost reduction in constructing the outlet structure.

In Example Problem #2, a much smaller pond can be accumulated. The ability of this pond to buffer the peak flow generated within the watershed is much less. The outlet structure in this case must handle roughly 3.73 m^3/s (132 ft^3/s). This represents 91% of the total incoming peak flow. An economic analysis of the project should be done. Increasing the size of the outlet structure may cost less than constructing suitable berms needed to form the pond or storage area.

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